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CANADA EXPANDS HER NAVY

ADDRESS BY REAR ADMIRAL (E) J. G. KNOWLTON, R.C.N.

CHIEF OF NAVAL TECHNICAL SERVICES

BEFORE

AMERICAN SOCIETY OF NAVAL ENGINEERS BANQUET

STATLER HOTEL, WASHINGTON, D. C.

2 MAY 1952

Rear Admiral (E) J. G. Knowlton, R.C.N.,
Chief of Naval Technical Services.

First of all it is my pleasant duty to thank you, Mr. President, and the members of the Council, for asking me to have dinner with you here in Washington on the occasion of your Annual Banquet, and giving me the great privilege of meeting personally and addressing the many members of your Society who are present tonight.

In his letter of invitation, Admiral Lonnquest referred to the primary aim of the Society as being the advancement of the art, science and practice of Naval Engineering, a subject of principal interest to the shipbuilding industry, and, in turn to those industries supplying the basic materials and the components that make up our ships. He also referred to the significant relationships between Canada and the United States, in these days of international stress.

Taking that as my cue, I think that I shall not be far off the beam if, tonight, I restrict myself to a review of industrial development in Canada generally, with special emphasis on the development of those industries directly concerned in the production of ships of war and their equipment, and attempt to relate the effect of this development to the Canadian industrial capacity for the support of maritime warfare. I shall follow on from there, with some observations on the current program and objectives of the Royal Canadian Navy, and throw in for good measure a few of my own views on how we are getting on up there.

First of all, what have we got to work with. What basic resources and materials are available to us as a supporting background for industrial development and production, a background which is so particularly important in time of war?

There is little doubt that the farther one gets away from Canada, the greater is the conception that Canada is a land consisting largely of forests and streams, of prairies, ice and snow, Indians and Eskimoes, and of course the Royal Canadian Mounted Police. Far be it from me to disabuse that conception too much, because I am told that it is a humdinger for the tourist business. Apparently we make a lot of dollars that way.

In any event it is, in many respects, true. Canada has been in the past and still is, one of the major granaries and stock raising centers of the world. In wheat we are the world's third largest producer, being second only to the United States and Soviet Russia —our actual production being a little below half of your actual production, which as far as we know approximates that of the USSR. Similarly, in forestry and forest products, Canada has a predominant position in the world production picture—both actual and potential. In accessible productive forest areas, and excluding the USSR, Canada is in third place to the United States and

Brazil—our accessible areas being roughly two-thirds of yours and four-fifths of Brazil's. In actual production, Canada is a close second to the United States in pulpwood, with Scandinavia in third place. In newsprint, Canada leads with 60% of world production, followed by the United States and Scandinavia with about 11% each. I would like to interject here, from my personal experience I can vouch that there is no paper shortage, at least in the Ottawa area.

And so we see that the embryo tourist conception is not too far out of line, and that Canada is indeed one of the world's giants in Agricultural and Forestry production. I forgot to add that, needless to say, we also have a complete corner on the market in the case of the Royal Canadian Mounted Police.

However, the view presented to our embryo tourist is far from complete and ignores a major transformation which has taken place in our national economy from one of agriculture to one of industry.

To illustrate my point—before the last war, even as late as 1939, more persons earned their living from Agriculture than from any other single occupation. In fact, there were approximately double the numbers employed in agriculture than in manufacturing, and about one agricultural worker for every one in conventional industry as a whole. Today, the numbers employed in manufacturing exceed those engaged in agriculture and the agricultural worker is outnumbered by the industrial worker as a whole by more than two to one. Incidentally, although during this period our agricultural employment has fallen off by some 25%, the actual agricultural output has increased—which I presume reflects the effect of industrialization on agriculture itself.

Now this is an astonishing transformation to take place in the relatively short period of 12 years. Undoubtedly, the largest single reason behind it all was the Second World War which demonstrated so clearly that modern warfare can only be as effective as the strength of the industrial effort behind it. The requirement was there, not only for our own Armed Forces, but for our Allies as well. It simply had to be met.

Let us, therefore, for the moment, forget about Canada as a land of forests and streams, of hunting, fishing, trapping, and of agriculture, important as they may be in our way of life. Let us instead look at the new Canada—Industrial Canada—with the respect due to the new leader in our economic life, and one who has proven its fitness for that leadership in no uncertain terms.

There is no doubt that the most spectacular of all industrial development has taken place in the Mining Industry. From the wave of exploration and development which followed the discovery of silver in the Cobalt area of Northern Ontario during the construction of the Timiskaming and Northern Ontario Rail-

way in 1903, and the further major impetus arising from the discovery of gold and base metals in the Noranda area of western Quebec, Canada's production has advanced to the state where we are now the world's largest producer of nickel, to the tune of some 95% of world production, of asbestos with 80%, and of the platinum metals. We are second in world production, to the United States, in aluminum (although from bauxite imported from South America), second to the United States in zinc; second to South Africa in gold; second in cadmium, selenium—the largest plant in the world is at Montreal—and probably second in radium and uranium, and fourth in copper and lead.

I would like to stress the importance of the non-ferrous metals, not only in relation to the mining industry as a whole, but also to the industries more immediately concerned with the production of defense equipment. Last year the total value of mineral output in Canada exceeded one billion dollars. Of this, smelters and non-ferrous refineries processed non-ferrous metals worth about half a billion dollars. This production, which was three times the value of the gold mined during the year, placed the non-ferrous smelting and refining industry third among the manufacturing industries, exceeded only by pulp and paper and meat packing. Canada has also been the world's leading exporter of non-ferrous metals for over ten years. The position, therefore, of the industry in the general scene, cannot be denied. What is more important, from a North American outlook, is the fact that important discoveries of new ore bodies are still going on—and the erection of smelting and refining facilities has not even kept pace with the discovery of new ore bodies—which justify the conclusion that Canadian mining developments in the field of non-ferrous metals are far from becoming static. In the United States, I am told, the picture is somewhat different—that very few new discoveries have been made since 1910, and that reliance must be placed in an increasing degree upon imports. Let no one, therefore, underrate the actual potential significance of the Canadian non-ferrous metal industry.

Now let me turn to iron ore, the essential background for practically all industry and in particular for defense industries. I think that the best way to describe what is happening in the extraction part of the industry, is to state that prior to the Second World War our output never exceeded 500,000 tons a year—a mere drop in the bucket and far short of our requirements. Compare this with our current production of over 4 million tons and a planned production of probably 15 million tons per year in 1956, and 25 million tons per year in 1960.

Also it is probable that this year, for the first time in our history, we will be a net exporter of iron ore, and in ten years, one of the world's leading producers; possibly ranking third behind the United States whose annual production rate, I understand, is

fairly steady at about 100 million tons, and Soviet Russia with an estimated output of about 40 million tons. Why is this possible? For three main reasons. Firstly, the discovery and productive development of high grade haematite ore at Steep Rock Lake in Ontario at the beginning of the war where, it is becoming increasingly apparent, lies one of the Western Hemisphere's largest remaining deposits of high grade ore. Known reserves have been estimated at 200 million tons, but responsible authorities have estimated that one billion tons may ultimately be mined there. Secondly, preparation for the development of fabulous quantities of high grade ore in the Quebec-Labrador boundary area, where known reserves are estimated at 500 million tons. However, as active exploration has only been under way for about four years, only a small proportion of the region's iron-bearing rocks has been investigated and no one can yet assess with any accuracy the ultimate possibilities. Railway construction from Seven Islands on the St. Lawrence to the area is proceeding rapidly and a large proportion of the 360 miles involved will be completed this year, and mining of the more accessible ore bodies started in 1954. Thirdly, the discovery at Allard Lake, Quebec, and only 27 miles from the St. Lawrence of the world's largest known deposit of ilmenite or titanium-bearing iron ore. Reserves are estimated at 200 million tons and by 1953, production capacity will reach an annual rate of half a million tons. At Sorel, Quebec, some 40 miles east of Montreal, the largest titanium plant in the world is being erected where the ilmenite is smelted into its titanium ore and pig iron content.

So—what a change from the pre-war picture in Iron Ore. From practically no production and no planned development to the position which I have just described. It is indeed an encouraging outlook for the future and for the production of steel for defense industries.

No reference to Mines and Minerals in Canada is complete without mentioning oil. In the short space of five years, the Canadian oil outlook has been completely transformed. For many years Canadian fields supplied less than 10% of the nation's crude oil requirements. Then in February, 1947, a well at Leduc in Alberta, blew in, and the lid was literally off. Developments which have taken place in Canada since that time, have been without parallel in Canadian experience, and millions of acres have been placed under permit or lease. Production has increased threefold and existing wells are now capable of producing nearly 50% of the nation's petroleum requirements. Even allowing for increasing consumption, it is confidently expected that we shall be self-sufficient by 1960. Proven reserves have risen from 70 million to 1½ billion barrels, and potential reserves have been estimated as exceeding 20 billion barrels. This, however, is only part of the story. Recent promising developments at the Alberta

Government separation plant at Bitumount in the McMurray area of northeastern Alberta, indicate the early commercial feasibility of extracting petroleum products from bituminous sand deposits. These tar sands contain the greatest known oil reserves in the world—being assessed by Canadian Geologists at 100 billion barrels and by the U. S. Bureau of Mines at 250 billion barrels. I think you will agree, therefore, that when I used the word "spectacular" in connection with recent developments in our mining industry, it was possibly an understatement.

Now let me get down to earth a bit. It is all very well having at hand these vast quantities of iron ore, non-ferrous metals and oil—but, by themselves, they do not build ships, weapons and materiel of war. Are we capable of moulding our vast natural resources into actual fighting equipment? Perhaps the best way to tackle that one is to describe briefly what are the future prospects for production in four industrial fields, which, when taken together, cover broadly the essential requirements for the construction and outfitting of a complete war vessel. I refer to shipbuilding, machinery, armament and electronics.

During the half century between 1840 and 1890, Canada owned and operated a vast fleet of merchant ships, with which she captured more than her share of the world's carrying trade. In 1878 for instance, we ranked fourth among the ship owning and building countries of the world, with more than 7,000 ships on the high seas. To interject a personal note, my paternal grandfather owned and sailed his own ships out of Saint John, New Brunswick, all over the world's trade routes. Those were the days of wooden ships and iron men which were a natural outcome of the ready availability of great virgin timber forests on the very shores of our Atlantic harbors. Such timber was particularly suitable for masts and yards, and apart from our own requirements, a large proportion of the masts and yards for the Royal Navy were supplied from the forests of our eastern maritime shores. With the coming of iron and steel ships, however, those happy days were over and shipbuilding in Canada suffered almost complete paralysis until the Second World War, with the exception of a brief period of resurgence during World War I. Shipyards were maintained, therefore, largely for ship repairs and the total number of persons employed were in the neighborhood of only three or four thousand. How did our shipbuilders respond on the outbreak of the Second World War to the demand for more and more ships—both Naval and Merchantmen? Listen to this. This is what was produced. For our own and allied Navies, 4 Fleet Destroyers (not quite completed by the end of the War), 122 Corvettes, 122 Minesweepers, 70 Frigates, 16 Trawler Type Minesweepers, 26 Transport Ferries, over 3,000 Landing Craft, 250 Tugs, over 4,000 Smaller Craft, and 3 Armed Merchant Cruisers by major conversion. For the Merchant Fleet:—320 Ten-thousand-ton Cargo

Ships, 13 Ten-thousand-ton Tankers, 43 forty-seven-hundred-ton cargo ships, 6 Thirty-six-hundred-ton Tankers, and 16 Maintenance Ships. Now this could almost be termed a miracle of achievement. Not only did the shipbuilders expand their employment from about 3,500 to 75,000, but in so doing they built, among other things, the ships which allowed our Permanent Force and Reserve Navy to expand from a total of 366 Officers and 3,477 Men to the wartime strength of almost 100,000, and whose efforts in no small measure contributed to ultimate victory over the enemy submarine in the Battle of the Atlantic. It was a mighty close call, though, and for the second time in 25 years, it was clearly shown—the hard way—that to be unprepared to meet in the early stages of a modern war, the offensive power of enemy submarines is to court nothing short of complete disaster. It was shown clearly, not only must competent anti-submarine forces be in being at the outbreak of hostilities, but also there must have been developed beforehand the tools and techniques in industry for production of efficient anti-submarine forces in volume with the least possible delay.

What does that mean in the light of the scale of submarine attack which might be expected today. What does it mean when we compare the havoc wrought by the German's submarine force, consisting initially of some 50-60 submarines, with the potential inherent in the existing Soviet fleet now built or building of perhaps some 500 submarines and a possibly even larger target fleet. What does it mean in the light of the development of the modern high speed true submarine. Among other factors it means this:—It means the production of an A/S escort which, compared with the corvette of the last war, is rather like comparing a high powered automatic rifle with a bow and arrow. It means that apart from an infinitely improved type of ship, we have to be able to produce more of them—sooner.

It was, therefore, a source of great satisfaction to us in the RCN, when our Government in 1949, approved the construction of three prototype first class A/S escorts—an order which has since been increased to 14. Particularly satisfactory to us, I think, because it was the first post-war order placed by any of the wartime allied Governments for ships of this type, which were to embody the results of experience gained in war with our assessment of new characteristics required to compete with latest submarine developments. Particularly satisfactory to us also because of official recognition at all levels that the tooling and training of industry for the production of modern, fully-equipped A/S escorts takes time, and that it would not be good enough to wait until hostilities are upon us before undertaking this task. Particularly satisfactory to us also, because we were thus given the opportunity, not only of adding 14 of the most modern A/S escorts to our peacetime force, but also of possibly even greater importance, of

intelligent and orderly planning for the production of these ships rapidly and in volume, if and when the necessity arises.

We are, I like to feel, making the best of our opportunities on both of these counts. While any detailed description of the characteristics of our A/S escort is obviously out of place on this particular occasion, I can best describe her generally as being the smallest vessel which, in our opinion, is capable of maintaining fighting efficiency against the most modern and immediately foreseeable submarine, under the weather conditions which prevail in the North Atlantic. This means, essentially, that we have concentrated on good seakeeping qualities at high speeds in tough weather. Particular attention has been given to anti-ice formation characteristics, and any seaman will be impressed by the absence of redundant equipment on the weather decks. The propulsion machinery is basically of British design, and although the first set of main machinery will be supplied from England, subsequent sets will be of Canadian manufacture and to North American Industrial Engineering standards and practices. The conversion from British to North American standards and production techniques, has been in many ways quite a headache—but that particular hurdle is now pretty well licked. Incidentally, our main machinery manufacturers have done an exceptionally fine job, and we expect that the first all-Canadian set will be delivered only about two months after the initial English one, which takes place in a few weeks time. At one time, we were subject to a certain amount of criticism for selecting an English design because of the difficulties involved in manufacturing to North American standards. The answer to such criticism was that this particular design was evolved specifically for the function which these ships will be expected to fulfill. Furthermore, the design was immediately available. As no other design of comparable characteristics and performance was even on the drawing boards elsewhere, I am sure that by our selection we saved at least 2 years in over-all production time.

In the case of Armament, Fire Control and Electronic Equipment, the general trend has been, depending on the lead time for Canadian tooling and production, to purchase initial supplies outside Canada, in order to get the first ship completed within a reasonable time limit,—concurrently, however, with the establishing of our own production facilities in practically all cases. I would like to dwell, for a moment, on the latter angle.

Always with the object in mind of ensuring capacity for volume production in war, many steps have been taken which would not have been taken if our object had been restricted to production requirements only of the present program. We have established a specific target production rate for Canadian wartime requirements, and we have made great headway towards attaining it—

not, of course, without appreciable additional costs to the current program.

For example, the shipbuilding contracts were awarded to all shipbuilders who are earmarked for that particular job in time of war, in order that snags may be ironed out by all concerned now, rather than later. A system of prefabricated unit construction has also been evolved which undoubtedly has added to the current initial production time and costs, but helps assure volume production, if and when it is required. I am satisfied that we will have little difficulty in attaining our target production rate of hulls. Probably the greatest strides are being taken in the establishment of the target machinery production rate. You will recall that the construction of only four destroyers was undertaken during the war and that these were in fact not completed by the end of the war. This was a major task insofar as the manufacture of propulsion machinery was concerned, but it was accomplished and accomplished successfully, and the experience gained has been of immeasurable value to our new program. However, in the case of the 4 wartime destroyers, a good many components of auxiliary machinery were obtained from England, and the crucial gearing component of the main propulsion units from the United States. This time in the case of our escorts, we have decided that everything should be produced in Canada, and a potential production rate established to meet our target figure. This has meant, in the case of gearing alone, the erection of what will be probably the finest hardened and ground gearing plants, not only in North America, but in the world, as an addition to the plant of one Canadian engineering company. This is almost complete. It means the extension of the main machinery manufacturer's plant to the required production rate capacity. This is well in hand. It means the addition of a 7,000-ton forging press at the plant undertaking the forging of our highly stressed rotor forgings. It means many other detailed features on the same pattern, all of which add up to a noteworthy addition to Canadian Industrial production capacity, and all to a target plan as far as the Navy is concerned.

Turning to electrics and electronics, we find that here we have the fastest growing manufacturing industry in Canada, and one which has grown no less than ten-fold since 1939. Prior to the Second World War, the industry concentrated its efforts almost solely on the production of broadcast receivers—apart from a small volume of communications equipment, the total production being valued at approximately $10 million annually. By 1944, the industry was producing electronic equipment valued at nearly $200 million annually, and had been responsible for the implementation of mass production techniques on many types of radar equipment. By 1950, the industry had developed its manufacturing facilities to the extent that all major or large volume items

embodied in electronic or radio apparatus were made in Canada with a varying degree of imported content. Many new firms, both from the United Kingdom and the United States, have established facilities in Canada during the past 6 years, to supplement even further our wartime facilities and know-how. This factor, together with the still expanding activities of our established industries, means that we are producing more highly developed equipment and sub-assemblies than ever before.

A typical and interesting example is the field of television where Canadian manufacturers are actually selling production parts to the United States. This year, in all, about 40% of the industry's capacity will be allocated to the production of defense equipment.

That it has been possible thus to expand in this field is, I am certain, due in no small degree to the extremely close link which prevails betwen the large Canadian companies and their parent organizations in the United States. I think I might say, therefore, that we have every confidence in our Electronics Industry. They have proven not only their willingness, but their ability to tackle successfully everything that we can throw at them.

Now, a word about armament and ammunition. During the last war, Canada produced vast quantities of materiel in these categories—the majority destined for our Allies, rather than for the requirements of our own Services, several key production facilities being established for the purpose in addition to the facilities which were made available by conversion of normal industrial capacity.

At the end of the war, and with the cut off in demand for such highly specialized material, the problem arose—what to do with these plants and their equipment. The decision was made by our Government, not to dispose of them, but to place them under the custodianship of a Crown Company, that is to say, a Government owned Company, to be called Canadian Arsenals Limited. In addition to maintaining custody of selected key facilities in the armament and ammunition field, Canadian Arsenals were charged with the responsibility of keeping abreast of new production techniques, and procedures, and act as a nucleus from which expansion and production of new weapons and equipment could be activated with the least possible delay. They were also allowed to get on with any production orders which came their way, not as a competitor of industry, but rather as the filler of a breech in Industry's willingness or ability to fulfill a requirement. Therefore, we have maintained really significant facilities in the field of guns, electronics, instruments, shells, ammunition filling, explosives and small arms. As a matter of fact, not only have we maintained them but, also, operations, particularly recently, have been extremely active, and our turnover has been in the order of many millions of dollars annually. I use the word "we," in a personal

sense, because along with certain well known industrialists, the three chiefs of the technical branches of the Navy, Army and Air Force, are members of the Board of Directors.

Well, Gentlemen, I have tried to give you a broad picture of our Canadian industrial capacity and potentiality, a potential which, if the pattern of the last war is followed, in another period of hostilities will supply $7 of its production of defense material to Allies for every $3 supplied to Canada's own Armed Forces. It is extremely important to remember that fact—that Canada's war production will probably be serving the requirements of our allies more than the requirements of our own services, by a ratio of more than two to one. In theory, therefore, and for maximum efficiency of the over-all effort we, in Canada, should be tooling for our largest customers rather than for ourselves who are a lesser customer, and it will be clear that the Industrial Mobilization problem in Canada is a complex one and relatively of much greater import from this aspect than that of the major powers, who mobilize primarily for their own requirement. However, in the case of Naval A/S escorts, we would appear to have nailed our colors to the masthead and have proceeded to tool up for our own class of ship, confident that as a type it is militarily acceptable right across the board. If any major changes, particularly with regard to propulsion, are required before our ship is acceptable to any other nation—I hesitate to estimate what might be the effect—not only on our own program—but also to the delivery dates which might be stipulated for outside orders.

I am compelled also to observe that quantitively our target production rate at the moment covers only Canadian requirements, and that tooling takes time these days.

Be that as it may, I think you will agree that we are making progress, and that our approach is a sound one.

Now a word about our Navy today. During the last war, as I have already mentioned, we, in the RCN, expanded from a personnel of about 4,000 to almost 100,000, and a fleet of some 400 operational ships. As you probably know, we were, above all, primarily an anti-submarine Navy, although our ships in one way or another were seen on all the oceans of the world except, I believe, the Antarctic. At the end of the war, demobilization—in common with many others—was rapid and for a short period, we were back practically to insignificance. However, we are now on the march again and are expanding to a reasonable effective fighting force for a country of our size. The wartime pattern is definitely again being followed in that our role is shaping towards specialization in A/S warfare. This, of course, in my humble opinion, makes sense, and there is everything to be said for a relatively small Navy such as ours, avoiding a diversified

effort and concentrating instead on attaining the maximum possible efficiency in one specialized field. Well—we are doing precisely that and it is difficult to think of any current activity in the RCN which is not directly or indirectly concerned with the development of A/S warfare capacity.

All of our existing destroyers are in the process of undergoing conversion, consecutively, and the modernization of submarine detection equipment and A/S weapons is No. 1 item on each list —although of course we are not neglecting other items such as A/A armament, communications, etc. We have recently also re-acquired a number of wartime frigates, and are carrying out an extensive modernization program on them—again primarily A/S. Our schools and tactical trainers are being modernized and re-equipped, and although this program is not fully complete —we think some features of our training devices will be unique in the training field. We intend to leave no stone unturned in achieving our objective of being on a par with the best in A/S warfare. We shall insist and continue to stress the need of ever-increasing the effectiveness of A/S materiel, and we shall train and continue to train until we are as near perfect as possible. We believe that nothing but the best will be good enough.

And now, Gentlemen, in summing up, may I say that tonight I have tried to give you a picture—a picture of a Navy, youthful in years but full of the enthusiasms associated with youth, a Navy which is small but conscious of the fact the smallness is only an incentive to greater efficiency.

I have tried to give you a picture of our shipbuilding—of shipbuilders of Halifax, that old garrison city, sometimes known as the Warden of the honor of the North—of Saint John, at one time one of the great shipbuilding ports of the world—of Quebec, center of our treasured French culture in Canada, and custodian of so much that is close to the hearts of all Canadians—of Montreal, the greatest metropolis of them all—of Toronto and other centers in the great inland seas of the mighty St. Lawrence Basin —of Vancouver, whose majestic harbor is Canada's gateway to the Orient, and to North East Asia—and of Victoria, the old Hudson Bay post—an origin so typically Canadian.

I have tried to give you a picture of our Navy, our shipbuilding and our other industries—all of them on the march in the common cause.

Our Objective—it is to build ships—good ships—worthy of the men who will man them, worthy of the cause which they may be called upon to defend—so that when the time comes and wherever we, in the RCN, may be called upon to serve, in any or all of the seven seas, we may acquit ourselves only with great glory and honor to Canada.

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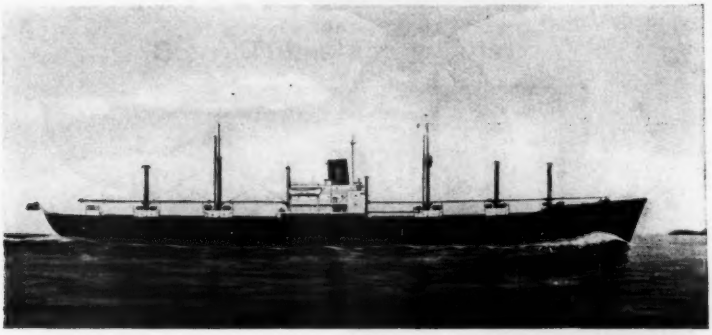

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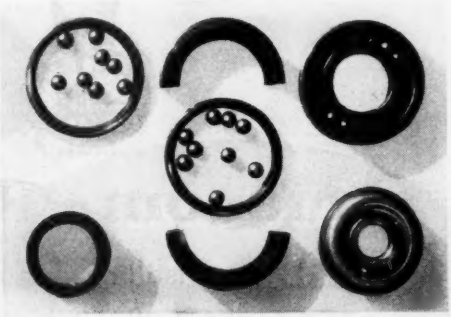

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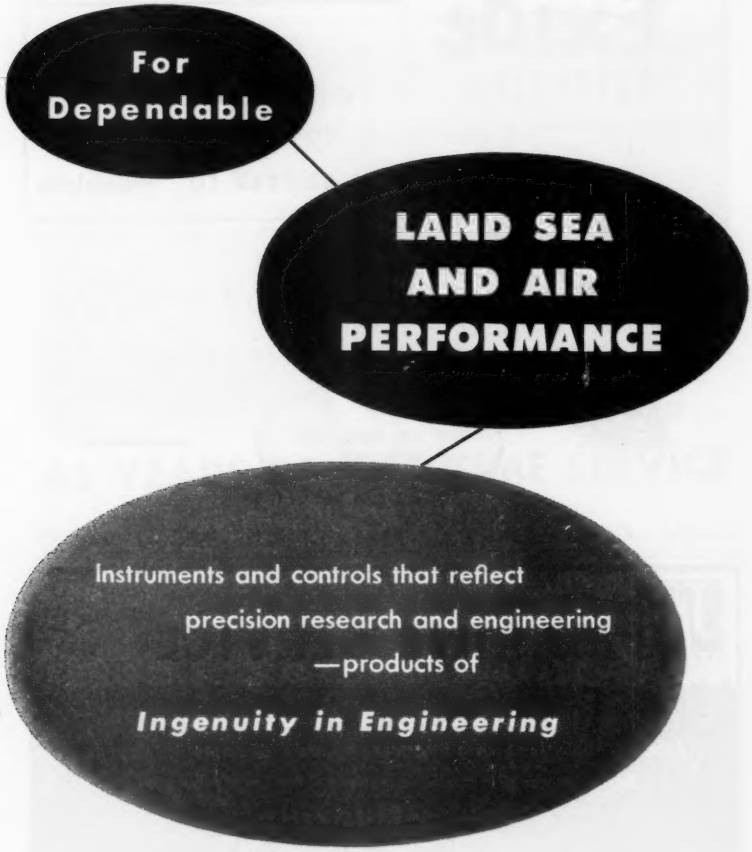

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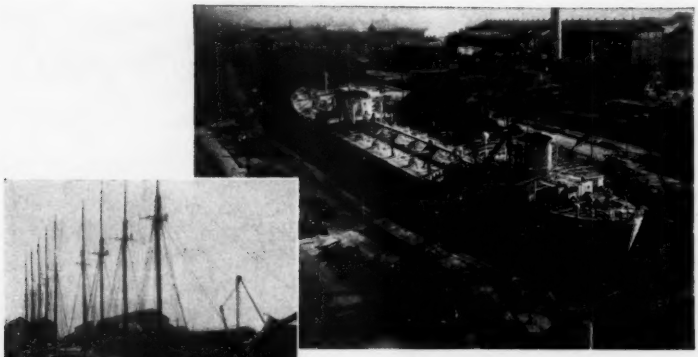

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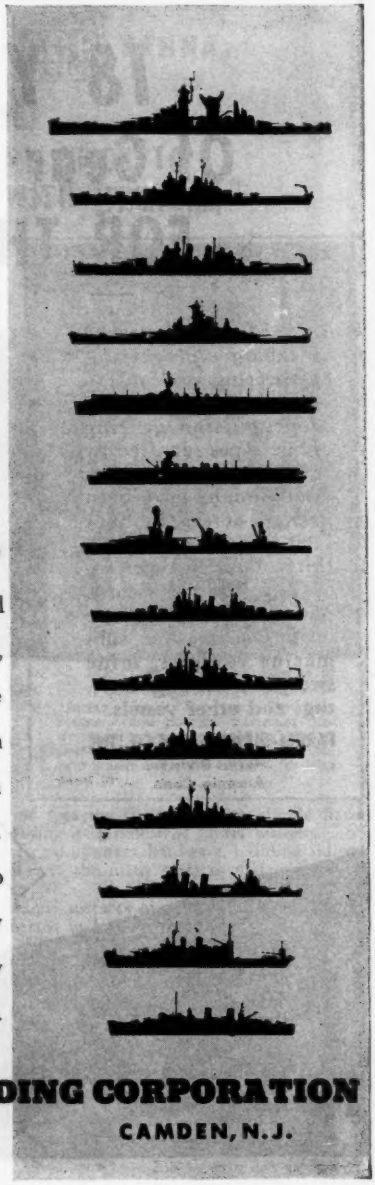

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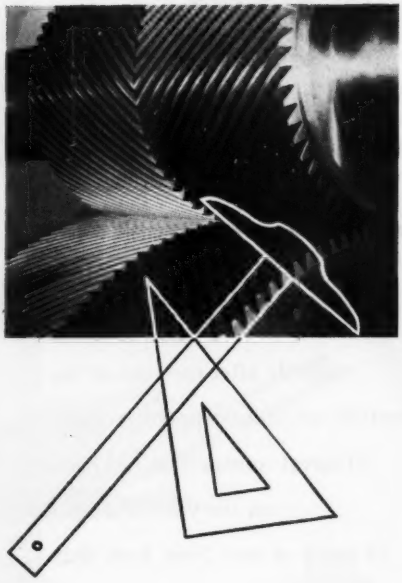

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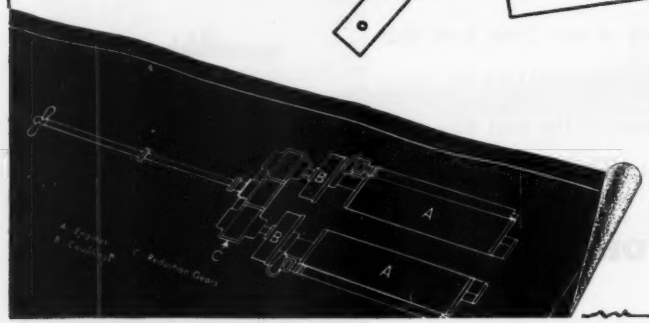

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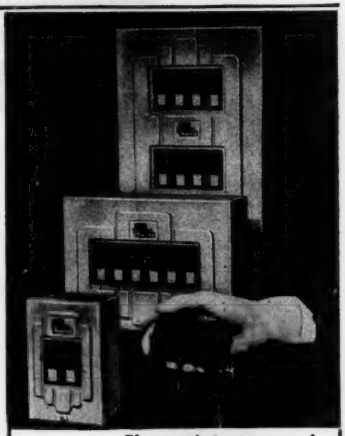

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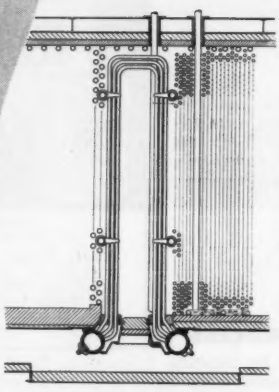
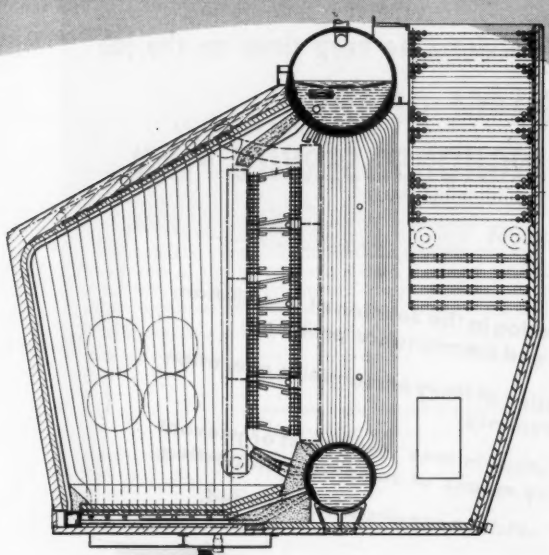


Plan view of "Walk-in" Superheater



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SECRETARY'S NOTES

ANNUAL BANQUET

Another successful banquet of the Society is now a matter of history. Members and guests who attended on 2 May 1952, again exceeded the capacity of the main banquet rooms of the Washington Statler Hotel and many had to be accommodated in the foyer and corridors: For the first time seating was arranged by order of application instead of by lot. However, members of more than twenty years standing were given special treatment.

The banquet meeting was presided over by the President of the Society, Rear Admiral T. C. Lonnquest, USN. Mr. Frank Nash, Assistant to the Secretary of Defense officiated as toastmaster. The principal address was made by Rear Admiral (E) J. G. Knowlton, R.C.N. Chief of Technical Services of the Royal Canadian Navy.

Several Past Presidents of the Society, the Secretary of the Navy, the Honorable Don Kimball and many others of note in the Naval and Naval Engineering fields attended.

LONGEVITY OF MEMBERSHIP

The Society is extremely proud and deeply appreciative of the fact that a great many of its members have been on its rolls for a long, long time. A check of the records show that no less than 120 have been members 30 years or more. During their entire membership they have given their loyal support and the Society is profoundly grateful.

Four members joined the Society in 1902 — 50 years ago. They are

W. E. Maccoun, Naval Member
W. S. Newell, Civil Member
Hugo P. Frear, Associate Member
M. L. Katzenstein, Associate Member

The following have been members 40 years or more:

Gregory, Henderson B., Civil Member, 49 years
Turner, J. B., Naval Member, 49 years
Dinger, H. C., Naval Member, 49 years
Powelson, W. V. N., Naval Member, 48 years
Cluverius, W. T., Naval Member, 47 years
Norris, Albert, Naval Member, 47 years
Ferguson, Homer L., Naval Member, 46 years
Kibbie, Austin S., Naval Member, 45 years
Cairnes, George S., Naval Member, 44 years
Anderson, Ernest H. B., Civil Member, 44 years
Doyle, M. A., Naval Member, 43 years
Powell, J. W., Naval Member, 43 years
Church, Albert T., Naval Member, 42 years
Woodward, Clark H., Naval Member, 42 years
Herbert, Frederick D., Civil Member, 42 years
Metten, J. F., Civil Member, 42 years
Robins, W. B., Associate Member, 42 years
Lord Weir of Eastwood, Associate Member, 42 years
Yeager, T. H., Naval Member, 42 years
Bagger, F. E., Naval Member, 41 years
Coman, V. K., Naval Member, 41 years
Cook, Fayette A., Naval Member, 41 years
Daniels, Milton R., Naval Member, 41 years
Johnson, C. H., Naval Member, 41 years
Beck, S. H., Associate Member, 41 years
Charlton, A. M., Naval Member, 40 years
Loeb, Leo, Associate Member, 40 years
Thayer, Horace H., Jr., Civil Member, 40 years

E. D. History

Captain Henry C. Dinger, USN Retired, has commented on "E. D. History" which was published in the November 1951 issue of the JOURNAL. Captain Dinger's letter follows:

"Capt. J. E. Hamilton, U.S.N.
Secretary A.S.N.E.
Bureau of Ships, Navy Department
Washington, D. C.

My dear Captain Hamilton:

In connection with your Staff article in the November 1951 number of the JOURNAL, I have a few comments to offer.

I think that it would give a better background if brief reference were made to the development of the special engineering courses which eventually grew into the Engineering Post Graduate School and out of this into the E.D.O.; also some reference to the Newberry system and the combination of the Bur. of C & R and Engineering in 1909, when Admiral Capps, Constructor, was Chief of both bureaus. During this time, when I was on duty in the Design division, I was asked by Admiral Capps to draw up a scheme for special training of young line officers for engineering duty. This I believe was the first definite plan to secure engineer specialists and to secure something definite out of the then P.G. system, where many were given special courses but very few were utilized for special engineering duty. However, since after some months of upset in Navy Yards and Bureaus, the Newberry system was terminated and Admiral Capps' suggestion for training line officers for engineering duty fell through. Some improvement in P.G. system, however, was made.

The references to S. M. Robinson as being the originator of the E.D.O. law is somewhat in error. During 1914-15, there was considerable discussion on engineering duty and I was then senior assistant in the design division. I was asked by Adm. Griffin to draw up a memo for E.D.O. legislation. This I did. The Admiral was also at the time concerned with other Bureau legislation. What I had drawn up was the legislation that eventually was passed in 1916. This did not go through at once. I left the Bureau in July 1915. I did not suggest the appointment of civilians as ensigns for engineering duty. This was added by the Secretary of the Navy, I believe, because it offered a chance for added officers and the extra numbers of E.D.O.'s also were extra new members. The law did not get through when first proposed but the second year it did go through. Adm. Dyson and S. M. Robinson at the time,

while favorable to the scheme, were not especially concerned with this then but Adm. Griffin did actively push the proposition and I suppose came to me to get the reactions of one who was likely to be affected.

It is quite possible that S. M. Robinson was active and effective in pushing through the final legislation but I drew up the memo which Adm. Griffin used. I also believe there is some error in including David F. Boyd in Engineering duty only. He was on duty in Bureau of Engineering 1913-14, but was not E.D.O. I took over his job, fuel and personnel, when he left the Bureau.

I may say that in the matter of Bureau of Engineering 1903-16 and engineering duty, there is much of which there is no record and where inaccurate ideas prevail. I started in the Bureau with Mellville. I was Dyson's relief in 1903 and Griffin was my relief in 1905. At this time the Bureau had no Chief Draftsman because the Navy Chief Clerk had this title so he could draw higher pay. There was no Officer Assistant Chief of Bureau. I made recommendations which finally resulted in getting an Officer Assistant Chief, chief draftsman, and additional civilian technical engineers for Bureau and its inspection offices, under Adm. Rae.

During this time there was the beginning of development of turbines, oil fuel, submarines, engineering and reliable water tube boilers, also hull and powering on the basis of experimental research including Taylor's work in hull lines and Dyson's work on propellers and the initiation of the Engineering Experiment Station. Also I had put in the first fuel consumption requirements in contracts for naval vessels.

It might also be mentioned that neither Chief or Assistant Chief of Bureau were E.D.O. for about ten years after law was passed.

Sincerely,

HENRY C. DINGER,

Capt., U. S. N., Ret."

Captain Dinger is correct about David F. Boyd. An error was made in including him among those who were designated E.D.O.

A.S.N.E. Membership as Prize

Captain Carl J. Lamb, USNR, has been mentioned before in these Notes. The following letter speaks for itself.

25 January 1952

"Dr. W. V. Houston, President
Rice Institute
6100 S. Main
Box 1892
Houston, Texas
Dear Dr. Houston:

Confirming our conversation of Saturday, 19 January, it affords me great pleasure to establish, for the duration of time that I am on duty here in Houston, a prize which I hope may be a slight incentive to some of your engineering students.

At the present time, the lives of all Americans are directly or indirectly affected by world conditions. Thinking people realize that two of the very important factors of maintaining our system of life and of safeguarding that system are the technical engineers, and the trained military personnel for reserve components. Rice Institute is progressively and objectively playing a leading part in both fields.

Accordingly, to that naval R.O.T.C. senior who is commissioned as an ensign in the naval reserve upon graduation and who stands first in the naval R.O.T.C. unit in mechanical engineering, I extend admission to and a year's membership in the American Society of Naval Engineers.

Attached is a copy of the last quarterly issue of the Journal of American Society of Naval Engineers. You will note that the last page in the journal gives the qualification for membership. The membership which I offer as an incentive would come under the first classification of naval membership rather than civil or associate.

I assume that upon the occasion of presentation at graduation some sort of a letter should be presented to the naval reserve midshipman who receives the prize membership. Since I have little knowledge of such procedure I shall appreciate receiving from you or Captain Mewhinney suggestions as to the format of that letter.

Sincerely yours,

Carl J. Lamb,
Captain, USNR.,
Supervising Inspector."

A.S.M.E. SYMPOSIUM

ASME Symposium on Shock and Vibration Instrumentation Planned for 1952

The Applied Mechanics Division of the American Society of Mechanical Engineers announced recently that plans are rapidly developing for a Shock and Vibration Instrumentation Symposium to be held during its summer meeting at Pennsylvania State College, State College, Pennsylvania, June 19-21, 1952.

Although the principles of operation, sources of error and methods of calibration of instruments will be stressed, a well-rounded program will be presented covering all fields of interest relating to current shock and vibration testing.

The program includes papers in the following categories: (1) Survey and historical; (2) One-degree-of-freedom instruments; (3) Sources of error and secondary effects; (4) Peak reading gages; (5) Calibration; (6) Applications. The symposium will close with a general discussion intended to bring out the difficult and intriguing problems which are in urgent need of solution in the instrumentation field and thus to stimulate further development.

It is expected that the symposium papers and discussion will be published in a single volume which will present the current state of knowledge on shock and vibration instrumentation.

MANUSCRIPTS

For some time, instructions for submitting manuscripts have been published in ASSOCIATION NOTES. The editor has on hand twelve manuscripts which have been submitted and which will be considered for publication in the August issue. Only four of the twelve were accompanied by a biography of the author. This omission will require additional correspondence, delay in acceptance and delay in the printer's part of the job. Prospective authors can help if they will refer to the instructions when submitting manuscripts.

SEA POWER

Base of American Policy

ACKNOWLEDGMENT

This article is reprinted from the October 1951 issue of The Marine Corps Gazette. The authors are COLONEL G. C. REINHARDT, USA and LIEUTENANT COLONEL W. R. KINTNER, USA.

The influence of sea power upon the growth of the United States is generally as underestimated as the extent to which sea power determines the fundamental foreign policy of this country today. Sea power, our own or that of nations allied to us, has played the decisive, if often unnoticed, role in all major crises of our history.

An inadequate understanding that the United States Navy is the basic tool of foreign policy contains several serious dangers. The first is an attitude of complacency that we will inevitably retain naval supremacy, and thus deny our Navy predominance in the technological development of sea warfare. Second, vital though the supporting role of sea power may be, the United States must fully comprehend the inherent offensive strength it can develop in its own right. Navies, to blockade the enemy, to safeguard the sea lanes, are not the complete concept. The ability to strike by sea at crucial points of a far-flung land empire has been too often neglected in the genesis of American strategy.

Every nation's foreign policy, like its culture, is the offspring of geography and history, though the degree each influences policy formation varies significantly. That the United States is an adolescent among nations, in a globe shrunk by technology, has made geography the most important factor behind American foreign policy. The outstanding geographical aspect of our position is that the United States is an underpopulated continental island separated by wide oceans from the teeming land mass of Eurasia-Africa. Irrespective of ideological cleavages, the foreign policy which springs from our geographical position is essentially this: The U. S. must prevent the dominance of the Eastern Hemisphere by a single power.

This policy requires a world balance of power as a logical development of, not a divergence from, our national tradition. Promulgation of the Monroe Doctrine warned Europe that we had adopted a balance of power policy for the Western Hemisphere. Our protestation of disinterest in Europe deceived no experienced statesman, but the success which followed that policy in the 19th century has been too much attributed to the respect it engendered in foreign gov-

ernment, too little to the benevolent neutrality of the British Navy.

The 19th Century opened with the destruction of the Napoleonic Empire, an almost successful attempt to unite the land mass of Europe under a single ruler. Repetition of that effort was not tried until the rise of Germany at the dawn of the 20th Century. Faced with the first German challenge we responded in emotional guise to an only vaguely understood danger. That time we called the struggle for a balance of power a conflict to "make the world safe for democracy." That war's bad scare caused us to place upon the high seas the world's mightiest Navy, its largest merchant marine. But because we were still thinking in terms of a hemisphere, not the globe, we permitted our Navy to reduce to a bare parity with Britain's, our merchant marine to dwindle to insignificance.

Our response to World War II was also instinctive, not reasoned. We entered, or were forced into, the struggle which we then termed a "war to end wars." In its process, our sea power grew until every facet of its strength exceeded that of any second and third powers combined. Victorious, we still avoided the basic issue. We emerged from that conflict recognizing too late that our own actions had predominantly contributed to the utter destruction of any semblance of balance on the Eurasian land mass. Belatedly, we admit stark fact; we are inescapably committed to preserving a world balance of power or face eventual national destruction.

As we re-enter the old struggle we must recognize that fire need not always be fought with more fire; water is often better. History, our own and that of past nations, assures us that the primary, though by no means only, weapon of an island people against a land mass is sea power.

THE AMERICAN POSITION

The United States has attained a rank among nations almost without parallel. The American people comprise only a small fraction of the globe's inhabitants, yet they command half the wealth and productive facilities of the earth. Unsought, almost undesired, power has been literally thrust upon the United States. Yet, coincident with accession to world eminence, the United States finds its security challenged by another nation whose ultimate power may exceed its own.

The appearance of the modern totalitarian state has made the threat of war a normal condition. The Kremlin has become in fact, as well as symbolically, the threat, not merely to peace, but to the freedom of every citizen in the non-Communist world.

Having at last accepted the implications of the jungle state of world politics, the United States has thrown itself into another hasty, costly effort to accomplish in weeks the re-arming that had been ignored for years. There is grave danger that the role of the Navy in United States security forces may be slighted, that the offensive potentialities of sea power may go undiscovered unless the relation between sea power and national strategy is fully understood.

Prior to 1939, American security rested on four pillars: its geographical position, its vast natural resources, the European balance of power, and the British command of the sea. Of these four pillars, the first has lost much of its meaning, much of the second has been expended, the third is irretrievably gone, and the main responsibility for command of the seas (and now of the air) has passed to our hands.

In a world whose political structure was altered almost beyond recognition by WW I, and in one in which the buffers of time and space have lost importance, American security has been anchored to two new foundations. These are reliance on our own strength, and military alliances with those nations of the world with whom we have parallel interests and share a common heritage. Maintaining our own strength and giving military assistance to our friends provides the ultimate support on which our other basic policies rest.

FOUR PILLARS OF AMERICAN FOREIGN POLICY

As power is the handmaiden of policy, an examination of the role of sea power properly begins with a survey of our underlying policies.

For the greater period of our national life we have adopted vigorous policies to secure the objective we prize. The policies we are pursuing today have deep roots in our past and are likely to be a guide to our actions in the years ahead. The major policies of the United States, which are characterized by a high degree of permanence, are: (1) To create a world order based on justice (now through the United Nations); (2) To further peace through promoting economic well-being; (3) to encourage the spread of democracy; and (4) pending the creation of a world order, to seek security through regional associations.

These are the main policies given to us by the marriage of our history and geography. Our history indicates the necessity for a much closer coordination between the execution of our foreign policies and our military capabilities. Our military plans are, and properly should be, subordinate to and contingent upon our foreign policies, yet it is essential that our foreign policies take into consideration our military capabilities or limitations. On this point the United States has often been remiss.

Plans for the employment of any of the armed forces are fundamentally unsound unless they contribute to the attainment of the national objectives sought by these policies. The four major policies just enunciated provide the political frame on which all military planning and development must rest. Specifically, the role of sea power must be defined in terms of our over-all military posture in time of peace and the military strategy pursued in war. Our military posture and our military strategy must both advance the goals of policy.

THE TOOLS OF POLICY

Two world wars and the even graver crisis following the second conflict have been necessary to convince the United States of the truism that national policy and power must be applied simultaneously along four lines; political, economic, psychological, and military. We are still amateurs at the fine art of combining those four methods compared to our aggressor adversary or, in fact, in comparison with many of our allies and defeated former foes.

Emergence of Soviet Russia as a super-state, embarked on a campaign of world conquest, has established the ultimate reliance of economic, political, and psychological factors upon military force. Yet no military campaign can be planned or conducted in a political-economic-ideological vacuum. Even totalitarian states respect the force of public opinion and expend vast energies in seducing it, not merely at home but abroad. For the end of policy during both peace and war

is always psychological, to induce the opponent to accept your way of thinking.

It is in the integration of political policy into the over-all national objective of security that we have most grievously failed to combine military capabilities with political pronouncements. Containment of Communism was accepted by the United States at the time that economies, even reductions, in defense budgets were most rigorously applied. Brave words, unsupported by military strength, are no better than outright appeasement. The counsel of a one-time assistant secretary of the Navy to "speak softly but carry a big stick" was often neglected.

Our military stature made it glaringly clear to thoughtful observers that our foreign policy was mainly backed by the unknown efficacy of atomic attack upon an aggressor. Even that potent weapon has not been exploited politically and psychologically to best advantage. It is impossible to convince a nation's people that we are foes of merely their unjust rulers while we threaten them and their families with mass destruction weapons that will injure neither the deep shelters of the rulers nor their aggressive armies. Only recently have we turned to the tactical development of atomic weapons. Yet in the preeminence of our technology and industry lies the most powerful weapon with which to defeat huge aggressor forces.

We have gone through a false dream of gadget-won victory, of single-weapon triumphs. For some time we have talked "balanced forces" but clear enunciation of the term is still restricted to highly classified areas. The American people do not understand to what levels of expansion our land forces, both Army and Marine, must be raised. They have but vague concept of the real needs of today's air force. Least of all, have they sound ideas of the development of our sea power along, according to post war standards, relatively "unconventional" lines. They vaguely accept the rebuttal of extreme air enthusiasts, and know that neither the carrier nor the battleship, with their protective screens, are passé. They do not know the potentials of submarine, and anti-submarine warfare, model 1951. The threat of bomber-placed mines to Britain's ports is still regarded in the light of the Battle of Britain rather than of Soviet capabilities.

Hostile possession of atomic weapons is considered only as a lethal danger to our cities and major industry. That it might close the essential ports of our Allies, even if not our own, forcing embarkation over friendly beaches, not merely such landings on hostile shores, is a new concept. That future development and cheapening of atomic weapons could render a lone ship at sea a highly profitable target is met with an ostrich attitude. If the heartlands of the aggressor are nearer our air bases (at least, while we retain them in the lands of our Allies) than are our own cities to the bomber fields of the attacker, we must realize that our tenuous supply line, stretching thousands of miles across sea and land, is at a disadvantage compared to the aggressor's relatively easier problem.

Just as the Air Force must be strengthened with the latest jet models in both quantity and quality, just as our new divisions must receive tanks and guns superior to those used in Korea, so must the Navy benefit by technological advances in sub-surface as well as air combat. Its auxiliaries may need shallow draft, higher speed ships to circumvent mines and submarines, and to handicap enemy bombers. The offensive striking power of the Navy must be increased, not merely by removal of WW II equipment from the "moth ball fleet," but by equipment known to our scientific planners if not to our public.

THE SOVIET THREAT

The secrecy with which the Soviets manage to maintain their military preparations as well as their precise political aims renders most difficult an objective evaluation of both capabilities and probable intentions. Recalling the embarrassment of our intelligence information about Hitler's strength, a weird mixture of vast exaggeration of military might and underestimation of industrial potential, cautions against accepting widely publicized accounts concerning either immense Soviet combat forces or inadequacy of their manufacturing or transportation support.

Should war ensue in the near future what are the limits to which aggression can be held? Effective invasion of the United States is definitely not a danger, though a sneak attack upon Alaska has some prospect of initial success. Atomic bombardment of selected targets within the United States, particularly by "one way" bombing squadrons is entirely feasible. Sabotage of our industrial systems is inevitable; only the degree of effectiveness remains in doubt. The abysmal failure of vaunted Nazi sabotage in the last war is no criterion. Communist penetration of positions of government and scientific trust signboard the risks of assuming impossible the far easier task of labor front infiltration, or, indeed, that it has not already occurred. It is not fantastic that a deliberately inspired campaign of red-baiting and widespread suspicion might be fostered to harm, in the long run, our production and mobilization effort as much as direct sabotage. We are dealing with hard-headed realists whose utter lack of scruples has survived successive crises.

But it is in Europe, and to a lesser extent in the Near East, that the short term menace of Communism looms largest. While Hitler did not "miss the boat" by invading Norway as was prematurely asserted, he did attempt too much with too little. So far, at least, the Communists have made no such mistake. They have contented themselves with carefully calculated, limited objectives, each targeted as a step toward their eventual goal, world conquest.

In an early war, it may be accepted that Soviet attacks upon the continental United States would be limited to "calculated risks" designed to disrupt our growing war potential more than they cost the attacker. Campaigns of conquest would be aimed at Western Europe, the oil resources of the Middle East, and neutralization, if not conquest of the British Isles.

In assaying the possible success of such a far-reaching, if still "limited," objective it is necessary to review the contentions of men whose thoughts have influenced world history in recent times. Is the world today still a world of Mahan's "influence of sea power upon history" or has the land mass geopolitical concept of MacKinder invalidated the rule of the seas? How much has the growth of air power, of modern land transport, weighted the scales in favor of the vast sprawling Eurasian land power over that of the American "island continent"?

SEA POWER TODAY

The failure of the United States to recognize the existence of the Russian threat during and soon after WW II parallels the slowness of this country to acknowledge the searching analyses of Mahan. The latter delay may be attributed to our national ignorance of sea power save for defending our shores from invasion, an understandable limitation of view in a people untouched with the urge for world power. The former error stemmed from a long freedom from

powerful neighbors which, coupled with our own peaceful intent, made the mentality of Communism difficult to comprehend.

But if this country and its leaders were temporarily blind in their trust of Russian good will, thoughtful men in Britain were not. At the very dawn of the 20th Century MacKinder challenged Mahan's theory of the preeminence of sea power with his warning of the growth of a single world empire rising from the heartland of the Eurasian continent. His immediate fear was Russia, then opposing the British Empire in many portions of the world. His fear, expressed nearly 50 years ago, was that of today's statesmen: a combination of Russia and Germany or the hegemony of one over the other as an unsurpassed threat to the entire world.

MacKinder admitted the strength of Mahan's logic but sought to rebut with the argument that Europe and Asia, in fact Africa as well, were a single land mass which, in the hands of a single power, could eventually generate such sea power of its own that the far smaller western hemisphere, although supported by "island outposts" in Britain, Japan, and Australia, could not oppose it.

From MacKinder's *Democratic Ideals and Reality*, written in 1919 to guide Britain in its settlement of World War I, rose the Nazi exploitation of "geopolitics." Avidly, Hitler seized upon the cryptic pronouncement, "Who rules East Europe commands the Heartland; who rules the Heartland commands the World-Island; who rules the World-Island commands the World." It is still a powerful argument, a sobering thought. There is no question of its influence on current Kremlin planning.

Almost overlooked in the cataclysmic events of 1944, Nicholas J. Spykman's (Director, Yale Institute of International Studies), *Geography of Peace*, sought to reconcile the apparently divergent teachings of Mahan and MacKinder. Admitting the progress of land transport, the "heartland's advantage of interior lines," Spykman studied the unfavorable climate, the limited resources, especially agrarian, in the heartland itself. He noted the geographical barriers that separated that heartland from the "Rimlands" bordering the oceans. Finally, Spykman insisted, the advantage of central position was relative. When the power that opposed the heartland must come from across the seas to battle on an otherwise undefended rimland the advantage went to MacKinder's heartland. On the contrary, a timely buildup of the indigenous rimland power multiplied the transport problems of the vast, limited communications net of the heartland. "What is true for India and China defended by British sea power," stated Spykman, "is no longer true if their military strength can be made a by-product of their own industrial development." The truth of that warning seems to have penetrated the Kremlin more than Downing Street or Pennsylvania Avenue. The relation of this principle to our Balance of Power policy is crucial.

Spykman viewed the rimland as a long-suffering buffer, alternately assailed by the sea power of the off-shore islands and the land power of the heartland. "Its amphibious nature lies at the basis of its security problems." It is Spykman's contention that there has never been a simple land power versus sea power struggle. Both World Wars were won by combinations of sea power and rimland strength against heartland concentrations, he contends. Spykman rephrases MacKinder: "Who controls the Rimland rules Eurasia; who rules Eurasia controls the destinies of the World."

The plausibility of this restatement is attested today by the power struggle for Eurasia rimlands in the Far East, the Middle East, and Europe. Communist aggression sees the possession of those areas as vital for its further march to world conquest. The western nations recognize their "vital interests" in the

last two, however much they may have miscalculated the stakes in China. The world situation today is, therefore, a Spykman concept, but it does not completely invalidate Mahan, any more than did Spykman's thesis. Bolstering the power of the rimlands to resist heartland aggression is today's task. That objective, as we have already discovered, demands a full appreciation of the Mahan concept of sea power.

Mahan's teachings stressed, more than any other point the eventual defeat of every nation which attempted to use sea power defensively, even when the defensive concept was so liberal as to include the use of sea power to protect overseas armies of invasion. Protection was not enough. Mahan was no more content with blockading the enemy's shores than Nelson was to remain outside Copenhagen, than the British fleet was to passively blockade the French in Africa after France fell in 1940. Had he lived, Mahan would not have approved the passive roles of the allied navies in 1914-1918. He would have pressed for a naval assault on the German submarine bases in preference to a mid-ocean anti-submarine campaign.

Still unappreciated by the United States at large, Mahan's influence fortunately survived strong in our naval leadership. This country's Pacific war against Japan was waged in the strategy of Mahan. Never did our Navy hesitate to fling itself against Japanese shore guns any more than it was reluctant to expose the conventional taboo "land based aviation's superiority to carrier based planes." Admittedly, the planes of a small carrier force cannot successfully challenge vastly greater numbers of hostile planes on shore but the innate superiority of fixed over mobile runways is less in the jet age of today than during the early dark months of WW II.

Should today's crisis become tomorrow's conflict the United States Navy must possess the well-rounded strength to pursue simultaneously *all* the tasks incumbent upon naval supremacy. Its final success depends without question upon close integration with United States' air and land strength. All three Services must receive the unlimited support of the entire nation, expressed through its industrial system and the people's willingness to work and sacrifice. But the Navy is more than our "first line of defense"; it can be the spearhead of our attack. Our front lines are in the rimlands. Our ability to defend those lines, to counterattack tellingly from them, depends upon the offensive might of our sea power.

Professional, as well as amateur surveys report the Russian capability to invade Western Europe, the Middle East, Scandinavia, even India and Japan, in one and the same moment. Even conceding this gloomy picture to be a true one, those attacks cannot all be pushed home with equal aggressiveness. Initial forces can be placed in position, but whenever reinforcements or supplies are needed, the transport problem of interior lines as vast as Asia's will make itself felt. Logistics are not wholly favorable to the heartland. Sea power can provide the mechanism for concentrating superior forces at the decisive places of the rimland. This is the great strategic possibility which sea power opens up to the West in the current struggle.

SUMMARY

Converting these theories of sea power into specific tasks for our own and our allied navies is no insurmountable problem. Priorities and emphasis upon tasks will, like land warfare, "depend upon the situation" but preparation to meet all of them can be made.

If, as many military men aver, a third World War may be in essence won or lost in its initial phases, it will be the

influence of sea power along lines which are developments of, not departures from, Mahan which will sway the balance to our favor. Time will always be necessary for the industrial power of the United States to develop the great land armies, the expanded Air Force required for complete victory. The U. S. Navy, with the help from land and air power available, is most nearly ready. Our task as a nation is to complete its preparation for its new role, to spearhead our national offense to the end that the costly backs-to-the-wall duty of "first line of defense" need never be assumed.

The demands of our policy in peace and of our strategy in war both require that we exploit the oceans of the world as highways, not cringe behind them as barriers. But neither the demands of peace nor the demands of war can be met unless we possess sea power in the broadest sense of the term. Seen in this proper perspective sea power emerges as the essential base of American policy.

TESTING COMPARTMENTS FOR TIGHTNESS BY USE OF COMPRESSED AIR

REAR ADMIRAL RALPH E. MCSHANE, U. S. NAVY

THE AUTHOR

Educated in public schools, Baltimore, Maryland.

Graduated from U. S. Naval Academy with class of 1921A.

Transferred to the Construction Corps in 1924.

Tours of duty included Bureau of Ships, Naval Shipyards, Supervisor of Shipbuilding Office, staff duty with the U. S. Submarine Force, and, during World War II, as Logistics Officer for the U. S. Task Force in Europe.

Commander, Portsmouth Naval Shipyard, Portsmouth, N. H.—1949-1950.

Presently Director of Planning, Bureau of Ships.

EDITOR'S NOTE

The complete article by Admiral McShane is too long for publication in a single issue of the JOURNAL. *Additional parts, including the two appendices, will appear in subsequent issues.*

PART ONE

References

(a) Bureau of C & R pamphlet, "Air Tests of Compartments of Vessels of the U. S. Navy," reprint dated January, 1922.

(b) Bureau of C & R letter S29-8(TB) EN7/A2-11 of September 20, 1933, to Commandants, all Navy Yards and all Superintending Constructors.

(c) Bureau of C & R letter A10/S29-8 (C & DC) of August 20, 1935, to Commandant, Navy Yard, Norfolk, Va.

(d) Norfolk Test Serial No. 188—"Air Tests of Compartments—Investigation and Experiments."

(e) Bureau of C & R letter S29-8 (C & DC) of June 1, 1938, to Commandant, Navy Yard, Philadelphia, Pa.

(f) Bureau of Ships letter S29-8 (Dz) EN28/A2-11 of March 11, 1941, to Commandants, all Navy Yards and all Supervisors of Shipbuilding.

Appendices

I. Mathematical Analysis.

II. Probable Accuracy of Past Determinations of Aperture Area.

SUMMARY

The importance of adequate compartment tightness needs no defense. It therefore is evident that the methods by which tightness is determined should be the best which it is practicable to employ and a careful survey of the methods now in use and suggestions for improvement seems desirable.

The discussion in the following paper concerns itself only with the subject of the tests of compartments for tightness by the use of compressed air. The discussion may be more elaborate than necessary for the immediate needs of the situation but it seems desirable to cover all phases of the problem in some detail as a matter of record and to provide a complete survey as a point of departure for any analyses which may be made in the future. The following specific aspects of the subject are discussed:

I. The mathematical theory upon which tightness determinations should be based.

II. The effect of heat transfer as a major disturbing influence on the accuracy with which tightness has been determined in the past.

III. The specific leakage phenomena which occur in practical testing.

IV.* The accuracy with which tightness has been determined in the past and recommendations for changes to improve accuracy.

V.* The varying standards of tightness which have prevailed in the past and which probably still exist.

VI.* A survey and analysis of past and present criteria of tightness and the recommendation of a new criterion.

* The sections in which these subjects will be discussed will be published in subsequent issues of the JOURNAL.

A summary of the discussion of each of these subjects is given below.

It is desirable to stress one fact in connection with this subject. There is no intention in the following discussion to advocate that entire reliance be placed in any theoretical treatment of the air testing problem nor to base standards of acceptability solely on observations of pressure drop. Instead, it is considered that the only satisfactory method of judging tightness when air tests are employed is a dual process consisting of:

First, a careful search of all boundaries and fittings in a compartment under pressure and the rectification of all discernible leaks.

Second, an observation of the drop in pressure in a given period of time. This step should serve to indicate the success of the prior search and corrective work, provide a *measure* of the degree of tightness which has been attained and indicate whether further corrective work is required.

In the end, however, the pressure drop and the subsequent interpretation based on it provide the only certain indication that the compartment in question is acceptable. Therefore, a careful analysis of the "measurement" of compartment tightness is worthy of consideration.

Theory—There is a great temptation to ignore theoretical analyses of the air testing problem and take recourse to empirical solutions. This practice hardly seems justified. The laws governing the action of air are well established and have been proved many times by a vast amount of experience. It seems desirable, in consequence, not to reject these laws completely but to determine how they can best be applied to the specific problem at hand. The rejection of accepted theoretical considerations implies, in a sense, the adoption of a *new* theory and it is not unlikely that illogical requirements will be the result.

The original mathematical treatment of air testing was given in ref. (a) and the methods based on that document stood the practical test of many years of experience. The analysis made herein is fundamentally the same as that of ref. (a). It still assumes that the only rational measure of the tightness of a compartment is the total area of the apertures through which the leakage of air occurs and that the basic problem of air testing is, in the end, to measure that area. There are introduced, however, two further developments:

(a) the past analyses have invariably assumed that the temperature of the testing air would remain sensibly constant. The present treatment assumes that changes in the air temperature—small though they may be—are significant and their effect should be embraced in the theoretical equations.

(b) the mathematical manipulation of the fundamental equations has been carried to a point where the drop in pressure or the aperture area, as the case may be, can be calculated directly from the known compartment volume, test pressure, time of observation and temperature changes. This development—really an extension of the method of ref. (b)—makes possible a simple graphical solution of the problem.

When the test pressure, the pressure drop and the time of observation are known simple graphs will determine the value of nA/V where:

A = the "fictive" aperture area, i.e., cA' where c is the average coefficient of discharge and A' is the true aperture area.

V = the volume of the compartment.

n = the "index" of expansion of the air within the compartment. This factor is determined by the temperature change in the air under the specific conditions which exist.

It is desirable to note that drop in pressure is a measure of the value of nA/V and not—as popularly supposed—a measure of A alone.

Heat Transfer—In the past it has always been assumed that the value of n is unity, i.e., that the temperature of the compressed air within a compartment either did not change during the period of test or that its change was small enough to be neglected. This assumption is not necessarily correct. In a compartment from which compressed air is leaking, two distinct phenomena occur simultaneously:

(a) As air leaks through the apertures the air which remains within the compartment is expanding and its temperature tends to decrease more rapidly than is recognized usually.

(b) Whenever the temperature of the air within the compartment differs from that of the compartment boundaries and material within those boundaries, a transfer of heat takes place and the temperature of the air undergoes a change. The temperature of compartment boundaries is subject to change of a significant order of magnitude and thus tends to change the temperature of the air within the boundaries by a significant amount.

The net effect of these two actions is a change in the temperature of the air and a concomitant change in its pressure which is *not* due to leakage. In other words, in the general case the value of n departs from unity. Pressure drop, therefore, is not a measure of A/V but is a measure of nA/V and if n is subject to substantial and unknown variations in practice the correct determination of A with even a poor degree of accuracy is impossible.

There is a sufficient amount of theoretical, experimental and practically observed evidence to suspect that in the usual conduct of air tests the value of n is subject to wide variations and its value, of course, is unknown. If air tests are to measure A with only reasonable accuracy a method should be adopted which compensates for the varying value of n.

Leakage Phenomena—It obviously is desirable to determine the true value of the aperture area in any compartment under test. Unfortunately, any theoretical analysis involves the introduction of an "ignorance" factor "c," the coefficient of discharge. The conditions are such that "c" values for the apertures which exist in air testing cannot be determined directly. In ref. (a) it was attempted to overcome this difficulty by assuming that the "c" for circular holes would apply also to the apertures in air testing. By analysis of the only data now existing, as given in ref. (d), it is concluded that this practice is not correct. In fact it seems possible to ascertain values of c which can be used to determine true aperture values. Therefore, in this discussion it is proposed to adopt values of cA′, which has been dubbed the "fictive" aperture, as the measure of tightness.

Accuracy—Any process in which acceptance is based on measurement of some quantity involves two steps in which accuracy is important:

(a) The assignment of a limit of acceptability. The question of tolerances is pertinent here. In general, the tolerances should be as small as the precision of the measurements to be made will permit.

(b) The measurement of the quantity. This should be accomplished with the best practicable accuracy in order that there may be reasonable certainty that the acceptable limits are or are not being exceeded.

An analysis of all the factors involved in air testing reveals that poor accuracy has prevailed in the past in both phases of the problem. There is little assurance that the "allowable" drops which have been assigned in the past promote the degree of tightness which was intended.

Worse still, the accuracy with which tightness has been measured is very poor. There really has been no way of judging whether a given compartment is very much more or very much less tight than the recorded data would appear to indicate. The principal practical importance of this condition lies in the fact that, in many cases, corrective work may have been undertaken at considerable cost in time and labor because inaccurate drop determinations falsely indicated the need for it.

It seems entirely feasible to improve the accuracy with which compartment tightness may be ascertained by methods which will involve a negligible increase in cost or effort. The chief sources of error appear to be due to two factors:

(a) Too little precision in the practical determination of the drop in pressure.

(b) The indeterminate effect of heat transfer which obscures the value of pressure drop due to leakage of air alone.

Both these birds may be killed with one stone by the use of a differential pressure gauge which is described in the discussion. The more precise determinations of pressure drop due solely to leakage should produce a number of advantages.

Standards of Tightness—Any comparison of the tightness tests of similar ships built at different yards will reveal a surprisingly wide disparity between the general average of results. It would appear that certain yards consistently strive for *air*-tight ships while others adhere to the original intention of ref. (a) and accept compartments in which somewhat lively air leakage exists but which are judged to be *water*-tight. The greater effort necessary to attain air-tightness is obvious and yards in which this standard prevails are penalized by added cost. Naturally, the standards should be uniform for all yards and the question of what these standards should be is important.

It would seem unreasonable to strive for air-tight compartments except, possibly, in tanks and for the shell of a ship. Elsewhere a much less rigid standard would certainly appear to provide a perfectly adequate degree of tightness. Here again, accuracy is a factor. If the degree of tightness can be measured quite precisely there is reasonable assurance that efforts may cease when *adequate* air-tightness has been attained.

It would appear to be in the interest of uniformity and the elimination of work of doubtful value to determine acceptable tightness standards and promugate them to all interested activities.

Practical Criteria of Tightness—It is well known that a compartment need not be air tight in order to eliminate leakage of liquids. Therefore, in general, a certain amount of air leakage can be accepted provided prior search of the boundaries has been made and all readily discernible leaks have been rectified. The question is "How much leakage of air can be accepted?"

Ref. (a) settled this question in a logical fashion but at the expense of a great volume of calculations which required a major expenditure of time and effort. A number of short-cuts have been devised to reduce the burden of calculations and the present method, promulgated in ref. (f), is extremely simple and is workable. That method, however, is open to several criticisms, the most important of which are:

(a) It is indefinite in the sense that no single criterion is applied to a given compartment. Instead, a range of acceptable drops in pressure is applicable in any given case.

(b) It is based on data which, inevitably, contain large inherent errors as previously discussed. The empirical criteria, based upon purely statistical analysis, incorporates these errors into the criteria. The lack of a rational basis for analysis results in what, in effect, is a false picture of

the conditions which actually existed in the past.

(c) The rejection of a rational basis for determining a criterion results in at least one unreasonable requirement; i.e., that, for example, a compartment tested with an air pressure of 4 p.s.i. is required to have a smaller aperture area than if it had been tested at 2 p.s.i. In other words, by reducing the test pressure, it is easier to get a compartment accepted. This is not a logical standard of acceptability.

The proper analysis to determine a criterion for tightness which is based upon past experience would seem to be:

(a) Determine the *aperture area* which existed when compartments were accepted in the past. It is implicit that these compartments were considered to be satisfactorily tight and, presumably, experience has indicated this to be the case. Therefore, such aperture areas are acceptable in the future in similar cases.

(b) Correlate these aperture values with some readily determinable characteristic of the compartments which will define their tendencies to leak air or, expressed otherwise, which will define the practicable requirements for *air*-tightness. The same characteristic applied to future compartments would define the allowable aperture area. The preferable characteristic would seem to be the area of compartment boundaries but the data on this is not readily available for past compartments. A reasonably satisfactory substitute is the compartment volume.

Therefore, it is proposed that A/V be used as a means of judging the tightness which existed in the past and as a criterion for the future.

The data used in arriving at the present criteria, ref. (f), were obtained for study. Using the pressure, volume, time and drops given therein, the value of nA/V was determined and nA versus V was plotted. When compartments of a given ship type were grouped according to "use," i.e., all storerooms on one plot, all crew spaces on another, etc., a reasonably orderly variation of nA with V is apparent. On the basis of this analysis it seems entirely satisfactory to assign a given value of nA/V to represent the practicable limit of air leakage which, being acceptable in the past, is acceptable in the future. Of course, the indeterminate value of N which existed in past tests cannot now be evaluated and it must be accepted that, probably, the average value for the large number of tests studied represents the average which will exist in the future.

On the basis of the analysis of past tests described above, definite values of nA/V are proposed as the basis for judging acceptable tightness. For example, for Cruiser Crew Space Completion Tests a "limiting" nA/V value of 14×10^{-7} is proposed. The complete scheme of judging adequate tightness then would consist of:

(a) Using appropriate diagrams, and knowing the assigned test pressure and limiting nA/V value, the corresponding "allowable" drop would be ascertained directly.

(b) The compartment in question would be searched thoroughly while under pressure and all discernible leaks corrected.

(c) The drop would then be ascertained and, if equal to or less than the "allowable" value the compartment would be accepted immediately. No attempt would be made to obtain an air-tight compartment.

(d) If the drop were greater than "allowable" further search would be made to discover and rectify leaks which previously had been overlooked. If it appeared impracticable to attain the "allowable" drop, as will happen in a few cases, the compartment is "extraordinary" and the test data would be referred to higher authority

for consideration. Its acceptability may be judged in one of several ways:

(1) it may be accepted arbitrarily on the assumption that it has been made as tight as practicable.

(2) a new "allowable" drop may be calculated by the method of ref. (a), although this procedure is undesirable.

(3) the compartment may be compared with nA/V values which existed in the past in "extraordinary" cases. Definite values are given in the discussion.

(4) it seems possible to develop a simple criterion of "extraordinary" spaces solely on the basis of the number of electric cables which pierce the boundaries. However, if this is feasible the data must be gathered in the future.

For the present it seems advisable to adopt the method in (3) above.

(e) At the conclusion of the testing program, simple charts of the data would be submitted to a central agency as a means of judging the tightness attained and to provide data for quickly revising the limiting values of nA/V.

The method proposed here is equally as simple to apply as the one now in use. It has the added advantages of being based on rational considerations and thereby represents truly the conditions which existed in the past. Furthermore, it is specific in its application to a given compartment and promotes uniformity of tightness standards.

I. INTRODUCTION

Compartments are tested under pressure for two reasons:

(a) To determine whether the structure possesses adequate strength to withstand the designed loading.

(b) To assure that leakage does not take place when the space is filled with liquids in normal practice or is flooded due to damage or accident.

It is with the second phase only that this discussion deals.

In the final analysis the tightness of a compartment can be determined with certainty only by filling it with the fluid it is expected to contain. Thus, for the majority of compartments, which are required to be water-tight, water is the most reliable testing medium. However, in many cases it is desirable from the standpoint of rapidity to employ a substitute testing medium; in other cases where material would be damaged by water it is necessary to use a substitute.

Compressed air has many advantages as a fluid for determining the tightness of compartments.

(a) It is "searching" and will escape through minute apertures.

(b) It provides a rapid and flexible means of testing. If compartments must be made tight from the inside they may be searched initially under low pressure by a man inside the compartment. If, after examination from outside, a compartment under air pressure reveals the need for further work on the inside the pressure can be dropped rapidly, the corrective work performed and the test pressure again applied with small loss of time. Water tests in the same circumstances are slow and relatively costly.

(c) Air will cause no damage to installed material which would be damaged by liquids.

(d) A compartment tested with air requires no cleaning and drying after the test is completed.

With any testing medium there are two fundamental methods of ascertaining tightness:

(a) Sources of leakage may be sought by searching the boundaries. When air is the testing medium, leaks may be found by sound, feel, the movement of a flame or by applying a soap solution. Regardless of the medium employed, this method does not guarantee that all leaks have been discovered and corrected.

(b) The *degree* of tightness may be inferred by observing the loss in the quantity of the testing medium. With air the loss is indicated by a drop in the air pressure. This method, of course, gives no clue to the location of leaks but it does indicate whether further corrective work is necessary.

In view of the great importance of adequate tightness both methods have been employed, each acting as a check on the other. Where compartments are tested by air there is no inherent visible evidence of leakage and the drop in pressure is, in the end, the most reliable indication of adequate tightness.

The magnitude of the drop in pressure in itself is no *measure* of tightness. This fact must be stressed because too often its importance is neglected. Tightness must be judged by the area of the apertures which exist in a given compartment and drop alone will not indicate this area. Intuitively it is clear that for a hole of a given size the drop will increase with test pressure and time of observation and decrease as the compartment volume increases. Thus, a given drop means nothing until it is translated into aperture area for the given conditions of test pressure, time and volume.

Clearly, the small apertures existing in ship compartments cannot be measured directly; they must be inferred on the basis of theory from the drop observations and the other known conditions. It is important to stress this fact because in air testing the correctness of the theory employed and the proper methods of its application are vital factors in the problem.

Theoretical considerations sometimes are brushed aside in favor of empirical solutions and in one analysis of air testing the statement was made that: "the technique of compartment testing does not appear to approximate laboratory conditions with sufficient similarity to permit the application of Charles' and Boyle's laws without a judicious choice of empirical constants." This viewpoint will not stand the test of logic if it is employed to justify the complete rejection of theory. Clearly, whether it is used in the laboratory or in a ship's double bottom, air still obeys the theoretical laws which have been proved by years of experience. If experience in air testing seems not to indicate this fact the proper approach should be a critical survey of the *application* of the theoretical laws. To ignore the theory which has been applied successfully in other fields and turn to purely empirical studies really implies an attempt to develop a new theory.

Past Solutions—The original theory and the methods of its application as given in ref. (a) is a sound approach to the problem and the number of years during which it was successfully employed attests to its *general* correctness. This method, however, involves a considerable amount of calculation and in the years following its adoption various expedients were adopted to reduce the labor. One such scheme was promulgated in ref. (b). Basically, the method of ref. (b) was the same as that of ref. (a); the difference lay in the presentation of the same data in a somewhat handier form.

As time passed certain discrepancies in references (a) and (b) were presumed to have been noticed. In particular, it was assumed that the standards of ref. (a) were too generous for more modern construction and, possibly, the theoretical treatment or the experimental constants employed were not correct. Consequently, in ref. (c) the Norfolk Navy Yard was requested to investigate

the entire problem to determine new criteria for tightness testing by air. The results of the ensuing tests were reported in ref. (d) which did not propose any new basic ideas but did provide new statistical data. It is not clear that any of the proposals made in ref. (d) were actually adopted. There is some evidence that certain of the statistical data were put into general use—a practice, incidentally, which would have created errors of considerable size inasmuch as the data were not applicable unless the entire scheme of ref. (d) was adopted.

At any rate, experience continued to indicate that results being attained in practice were far better than were contemplated by ref. (a) and, despite the labor involved in that method, its standards of tightness were presumed to be too generous.

In order to improve conditions the Bureau, in ref. (e), requested the Philadelphia Navy Yard to undertake a new analysis of the problem with the objects of:

(a) Exploring the possibilities of devising new criteria which would reflect the results attained in practice.

(b) Developing a method of assigning "allowable" drops without the relatively slow and laborious calculations which previously had been required.

As a result Philadelphia analyzed the results of air tests on a large number of ships and, rejecting all theoretical considerations, proposed a purely empirical criterion based on data applicable to the specific ships which had been studied. The proposed method was adopted by ref. (f) and is now in effect.

In addition to the formal investigations outlined above it appears that many other analyses of the air testing problem have been made and a number of short-cuts have been devised. Some of the methods appear to have had firm theoretical bases, others have not been quite as rational but, at any rate, the number of investigators indicates the probable importance and the certain fascination of the question. The following discussion is only the latest in a long line of analyses.

Proposed Methods—It is considered that certain of the assumptions which have been made in the development of past theories result in errors of undesirable magnitude in the practical ascertainment of compartment tightness. On the other hand, the complete rejection of a theoretical basis for analysis as was done in the development of the present criteria is not satisfactory and, despite the seemingly increased rigor of these new standards, there still exist important inherent errors. Furthermore, it is considered that the present testing *methods,* regardless of the theory involved in the development of criteria, are too inexact for practical use and that a great deal of useless but costly and time-consuming labor may be expended as a result. Therefore, the following discussion embraces:

(a) A re-examination of the fundamental theory; analysis of the assumptions made in past theories; recommendations for new approach to the theoretical problem.

(b) The disclosure of simple graphical solutions of the theoretical equations which provide an immediate solution without arithmetical calculations.

(c) An analysis of the large probable errors which have existed in past determinations of compartment tightness. Practical methods for more precise determination are proposed.

(d) An examination of the varying standards of tightness which probably have existed between building yards.

(e) An analysis of the various criteria for criticizing the results of air tests. A rational and simple analysis of the results of past tests is made and, based upon it, specific criteria

are proposed to replace those now in effect.

The discussion probably is more complete and detailed than is necessary for the immediate purposes in view but the amplification is considered desirable in order to justify the adoption of new ideas. Without doubt there will be disagreement with many of the statements made but, insofar as possible, these statements have been based on statistical data which are included in the discussion, and dissenters may draw their own conclusions from the data.

II. THEORY

The problem—The purpose of tightness air tests is to determine whether a given set of boundaries will prevent the leakage of liquids to the adjacent spaces. Leakage can take place only if apertures exist and the problem becomes a dual one of:

(a) a simple qualitative question of whether or not any apertures exist. The answer to this query when air is the testing medium is not always as readily ascertained as may seem, at first glance, to be the case.

(b) If apertures *do* exist it is very desirable to determine their collective area in order to judge whether or not corrective action is required.

The first question is answered, in general, by an actual search which will reveal gross air leakage but may miss minor apertures. In any event the apertures are so small that their area cannot be measured directly. It becomes necessary, then, to infer the area from measurements which are practicable and on the basis of theory. Inasmuch as theory is the basis of the inference it is necessary to subject it to critical analysis.

General statements—The mathematics of air test theory are not of general interest and consequently have been relegated to Appendix I* wherein all the assumptions which have been made and the detailed development of equations are set forth as a matter of record. The methods used in Appendix I may not win the approval of competent mathematicians but the equations which have been evolved are believed to be satisfactorily accurate for practical use. The following discussion is merely an outline of the development of the theory, the evolution of the equations and their significance in order to form a basis for subsequent discussion of practical considerations.

There is little originality in Appendix I. Essentially, its contributions are:

(a) the rejection of the assumption that the temperature of the compressed air in a compartment under test will remain sensibly constant. Instead, it is assumed that it will change during the period of the test and that the effects of such change should be embodied in the equations. The question of importance is whether the effect of temperature changes is of significant magnitude.

(b) the methods used are entirely analytical instead of incorporating graphical devices as part of the mathematical development. This facilitates explanations and analysis of the effects of various factors. It also facilitates criticism.

(c) the development is carried to a point where the equations are susceptible of simple and rapid *numerical* solution by graphical or mechanical methods—a feature lacking in previous methods.

The equations reproduced in the following description are identified by the number used in Appendix I.

* EDITOR'S NOTE: Appendix 1 will be published in a later issue of the JOURNAL.

The solution—The compressed air in a compartment under test may be considered a "perfect" gas and mathematical analysis of the phenomena may be made on the basis of the laws which apply to such gases.

In the *general* case the compressed air in a given compartment undergoes the following changes:

(a) its mass decreases as a result of leakage through the apertures to the atmosphere.

(b) the temperature of the air changes due to the simultaneous effect of:

(i) the expansion resulting from leakage.

(ii) the heat transfer between the boundaries of the compartment (and the material within the boundaries) and the compressed air.

At any given instant the compressed air conforms to the fundamental gas law:

$$pV = RWT \qquad (1)$$

where

- p = the instantaneous absolute pressure
- V = the instantaneous total volume of the air
- R = a constant
- W = the instantaneous total weight of the air
- T = the instantaneous absolute temperature of the air.

For a given compartment V is constant; therefore, an air test, in general, is marked by a changing pressure, weight and temperature. If two of the variables can be expressed in terms which can be measured or safely assumed, the third can be calculated from equation (1).

On the basis of the common equations of air flow through an orifice and with suitable assumptions the weight of the air at any instant can be expressed

$$W = W_1 - BcAt\,[1 - E\,(cA/V)\,t] \qquad (18)$$

where

- $W_1 = p_1V/RT_1$ the weight at the *start* of the test.
- B and E are constants depending on the "test" pressure, i.e., the pressure at the start of the test.
- c = the coefficient of discharge in the apertures.
- A = the area of the apertures.
- t = the elapsed time.

Based on the common equations for heat transfer, and with suitable assumptions to fit practical conditions, the *change* in air temperature during the course of the test can be expressed

$$y = Na + Pmt - NFcA/Sh \qquad (26)$$

whence

$$T = T_1 + y \qquad (26c)$$

where

- T_1 = the initial temperature of the compressed air.
- y = the change in temperature.
- N and P are constants in a given case and are dependent on p_1, t and S/V; the latter being the ratio of the compartment surface area to its volume.
- F is a constant dependent only on p_1.
- a = the temperature difference between the compressed air and the compartment boundaries at the *start* of the test.
- m = the rate of change in temperature of the boundaries.
- S = the area of the compartment boundaries.
- h = the coefficient of heat transfer.

By substituting equations (18) and (26c) in equation (1) and making suitable transformations, the following eqation is evolved:

$$d = D(cA/V)\,t\,[1 - E(cA/V)\,t] - Qy \qquad (29)$$

where

- d = the *drop* in pressure, i.e., d is positive for a decrease in pressure.
- D, E and Q are constants depending on the test pressure alone.

Within the limits of the assumptions equations (26) and (29) are exact rep-

resentations of the phenomena. Appendix I includes calculations made with these equations to show the probable extreme conditions encountered in practical air testing. It may be concluded, if the analysis in Appendix I is acceptable, that temperature changes are of practical importance and that the pressure drop alone is an unreliable basis for inferring the aperture area.

Equations (26) and (29) may further be modified to produce an equation of greater utility by assuming that during the progress of the test

$$pv^n = p_1v^n{}_1$$

Where

v = the specific air volume in cu. ft. per lb. The subscript "1" indicates values at the start of the test.

n = a constant depending on the pressure drop and the temperature change in the time t.

By manipulating the various equations, the result is

$$d = Dn(cA/V)t\ [1—E(cA/V)t] \qquad (32)$$

And, finally, this equation can be approximated with satisfactory accuracy by

$$d = n[M(cA/V)t]^{0.984} \qquad (35)$$

Where M is a function of p_1. The virtue of this equation is that it is a form suitable for quick solution by simple methods.

Except at very low pressures and for long periods of time it is sufficiently accurate to consider E(cA/V)t to be zero and to represent equations (32) and (35) as

$$d = Dn(cA/V)t \qquad (33)$$

This form will be used in much of the subsequent discussions.

Lest the profuse mathematics of Appendix I appear too impressive, let it be said promptly that equation (33) is merely the equivalent of the "K" curve of reference (b) for, if n is taken to be unity (the proper value if the temperature remained constant)

$$K = Dtc$$

It may be noted here that the "K" curve of ref. (b) is quite inexact. It was prepared on the perfectly tenable assumption that the rate of change of pressure is sensibly constant for the relatively small drops and relatively short periods of time which are usually encountered in practice. However, instead of employing the rates of change in pressure already embodied in Curve A of ref. (a), the values used in ref. (b) were obtained from the "pressure versus time" curve of ref. (a) by taking the *average* rates for pressure drops which were vastly greater than are experienced and for which the rate of change is far from constant. This error is typical of others which have been made in various analyses of air testing where conclusions are reached too hastily on the basis of plausible (but incorrect) assumptions, inadequate investigation or misinterpretation of facts.

Aside from the inclusion of n to represent the effect of temperature changes, the advantage of equation (32) and its equivalent, equation (35), is that they make possible the presentation of the air testing equations in graphical forms which, compared to former methods, are more complete in scope, are more exact and are handier to use. The graphical solutions eliminate the need for much of the calculation which was a major source of criticism in the past.

The practical problem is two-fold:

(a) Knowing cA, V, p, t and n, to determine d. This is the problem of assigning "allowable" drops on the basis of "allowable" apertures.

(b) Knowing d, V, p, t and n, to determine cA. This is the problem of inferring the aperture area on the basis of the "observed" drop in a given case.

The simplest form of graphical solution (not the most rapid to use, however) is shown on a semilog plot of pressure drop against test pressure (gauge). The objectionable feature here is that the coordinates are *ratios* and further cal-

culation is necessary. A complete chart solution is described in Appendix I, which eliminates all calculation but its employment may be somewhat confusing and it does not afford the most rapid solution. The slide rule described in the Appendix is, by all odds, the most desirable device. It is not difficult to use and its construction is simple. The use of a similar rule in past years would have saved a vast amount of calculation and might have promoted the earlier adoption of revised methods for criticizing compartment tightness.

Reverting to the fundamental problem —that of determining the aperture area —equation (33) may be written

$$A = (1/n)\ (1/c)\ (V/Dt)\ d$$

The factor D depends only on the test pressure and thus always is known; V, t and d are measured quantities. Before A can be determined, however, the values of n and c must be ascertained. Both quantities are subject to wide variation in practice and their significance is believed sufficiently important to warrant separate discussion.

III. HEAT TRANSFER

Past analyses of the air test problem have been based on the assumption that the temperature of the testing air either did not change or that the change would be small enough to be neglected. This is a tempting assumption. It is true that, judged by the magnitude of the temperature changes of ordinary experience, those which occur in the compressed air during the period of the usual compartment test are very small. In passing, however, it is interesting to note that the changes in *pressure* which are considered significant also are very small. For instance, a drop of ½ oz. at a test pressure of 2 p.s.i. (gauge) constitutes a change in *absolute* pressure of only 0.2 of 1 percent. Pressure changes, though, are measured by manometers which are quite sensitive instruments; small changes in pressure are observed with considerable accuracy and we grow accustomed to them. Small but significant temperature changes, on the other hand, are not likely to be detected readily by the usual types of thermometers. There is rather general agreement among experienced personnel that temperature changes do occur, and the inter-relation between temperature and pressure is generally recognized, but the temperature question usually is dismissed on "intuitive" grounds as being of no practical importance. The following discussion is not conclusive of the fact that significant temperature changes do occur because there seems to be no direct evidence in existence but there will be produced a number of facts which, in their entirety, seem to build up a pretty good case of circumstantial evidence.

Fundamental phenomena—The change taking place in the air within a leaking compartment can best be explained by an analogy. Consider a perfectly airtight tank fitted with a valve to control the escape of air. Assume that the inside of the tank is perfectly insulated in the sense that no heat can be exchanged between the tank structure and the air within the tank. Let the tank now be charged with compressed air at the same temperature as the tank boundaries, 60° F (520° absolute).

(a) Now crack the valve and allow air to escape for a period of time; then close the valve. The mass of air remaining in the tank after the valve is closed now fills the tank; whereas initially it occupied only a portion of the tank volume; i.e., the air has expanded. Since the tank boundaries are perfectly insulated the expansion has been adiabatic and the air temperature will have fallen according to

$$T/T_1 = (p/p_1)^{0.286}$$

where temperatures and pressures are

absolute values. The following surprisingly large decreases in temperatures in degrees F *per oz.* pressure drop will take place:

Initial pressure (p.s.i. *gage*)	1	5	10	15
°F fall per oz. drop in pressure	0.6	0.5	0.4	0.3

Thus, the temperature of the air, in general, will differ from that of the tank structure.

(b) At this point consider that the insulation is removed from the inside of the tank. In general, the temperature of the air and of the boundaries will differ and an exchange of heat will take place tending to bring the temperature to a common value. Three situations may exist:

(i) If during the period air was escaping the temperature of the tank rose, stayed steady or did not decrease as much as that of the air, the temperature of the air will rise and its pressure will increase. If the temperature of the tank boundaries rose sufficiently, the air temperature could increase to a degree where the pressure would be equal to or even greater than the initial pressure.

(ii) If the tank temperature had decreased the same amount as the air temperature, no heat transfer would occur and the pressure of the air would remain steady. Its temperature, however, would be lower than it was originally.

(iii) If the tank temperature fell sufficiently, a transfer of heat *from* the air would take place, its temperature would further decrease and its pressure would decrease below the value existing when the valve was closed.

Thus the change in air *pressure* alone is not a measure of the loss of air due to leakage; heat transfer also affects the pressure. The heat transfer described here takes place while the air remains at constant *volume* and

$$T/T_1 = p/p_1$$

The following significantly large changes in pressure in *ozs.* per sq. in. *per degree* F change in air temperature would take place:

Initial pressure (p.s.i. *gage*)	1	5	10	15
Ozs. per degree F	0.5	0.7	0.8	1.0

In practice the phenomena described separately above are taking place simultaneously. The final temperature and pressure of the air depends on the net effect of both leakage and heat transfer. But is heat transfer a *practically* disturbing influence? The question will be discussed in the following phases:

(a) The factors which create and affect heat transfer.

(b) A theoretical analysis of the problem from which are drawn some tentative conclusions of the practical conditions.

(c) Practical evidence to support the belief that heat transfer creates significant aberrations and to roughly confirm the theoretical analysis.

(d) The probable situation existing in practical air tests.

Factors in heat transfer—Heat transfer is a matter depending on temperature difference. It is clear that a difference tends to be created merely by the fact that air leaks from the compartment but it can also be created if the temperature of the compartment boundaries and of the material installed within the boundaries undergoes a *change* during the test. Unless they are independent sources of heat (a situation which should not exist) the materials installed within the boundaries receive heat only from the boundaries. Thus, conditions which serve to change boundary temperatures are the key to the situation.

The boundaries of a given compartment cannot be considered as isolated structure; they are part of the entire ship's structure and fluctuate in temperature—not necessarily uniformly—with the changes in the entire structure.

Heat is constantly being added to the ship by rivet heaters, welding arcs, gas torches, steam coils, electric current and other independent sources. Structure exposed to direct rays of the sun receives, during daylight hours, large quantities of heat and undergoes relatively large temperature increases due to solar radiation. Simultaneously heat is being extracted from the ship by radiation and conduction to the atmosphere (in regions where ambient temperature is lower), to ways structure, to the water when the ship is afloat, etc. None of these sources of added heat nor the reservoirs which extract heat are constant in their effect and the net result is undoubtedly a constant fluctuation of boundary temperature which probably varies in character depending on a great number of factors. For a given compartment under test it is conceivable that the *changes* in boundary temperature are affected by whether or not the boundaries are directly exposed to the sun, or their proximity to structure which is; the presence and character of insulation; the quantity and kind of material within the boundaries, and the size and character of faying surfaces.

It is probable that the effect of atmospheric temperature (independent of the effect of direct solar radiation) is a major factor. So far as a given ship is concerned the atmosphere is an infinite source or sink for heat transfer depending on whether the ambient temperature is above or below that of the structure. Inasmuch as heat transfer between the air and metal takes place at a lively rate it is likely that, other sources of heat being remote, the boundary temperature will follow the atmospheric temperature rather closely and, particularly for compartments adjacent to the ship's envelope, the atmospheric temperature change is an important factor. These changes are greater than is commonly realized. The attached graphs, Figs. 1 and 2, show data for the Philadelphia area taken from the Weather Bureau records for October to December, 1942 and January to September, 1943. There are plotted

(a) for each quarter of the year faired curves showing the *range* of *hourly* temperature *changes* for each hour of the day.

(b) for each quarter of the year the "distribution" of recorded changes for selected daylight hours, viz. 0800, 1200 and 1600. As would be expected, this distribution is approximately the curve of probability with a high frequency of an average value and rapidly decreasing frequencies of changes greater and less than average.

While these data are for a particular region during a particular period of time, the fact that they show *changes* in temperature make it seem likely that they are qualitatively representative of general conditions and possibly are reasonable quantitative pictures. At least certain characteristics which are interesting are apparent.

(a) Fall and winter conditions are approximately the same in character and differ considerably from spring and summer conditions.

(b) The *greatest* rises in temperature seem more likely in winter, but the *average* rises in summer are greater.

(c) The *range* of most likely temperature changes during daylight hours is greatest in summer. This situation leads to an interesting speculation. Suppose a test gang started to test a compartment at 0800 on a summer day when nature was against them. Their first observation exceeds the allowable drop. They've had some benefit from a moderately rising temperature but they are not aware of it. They search for, find and correct some leaks. They observe the drop again but now the temperature doesn't rise as rapidly; the drop still exceeds the allowable and they start the cycle again. If toward the end of the day

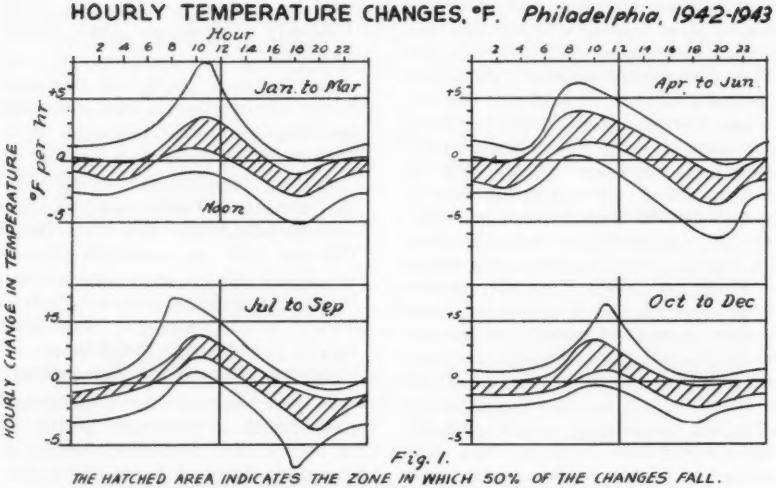


Fig. 1.

THE HATCHED AREA INDICATES THE ZONE IN WHICH 50% OF THE CHANGES FALL. THE UPPER AND LOWER CURVES MARK THE ZONE IN WHICH 90% FALL.

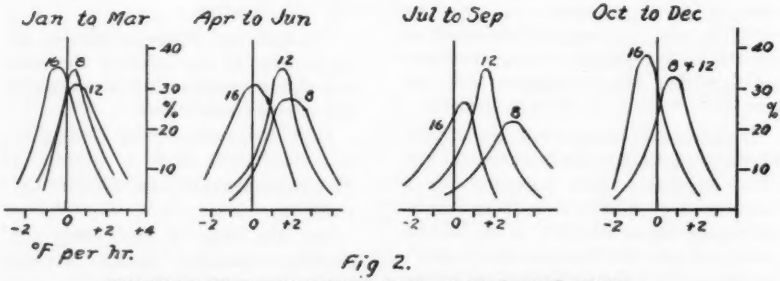


Fig 2.

FREQUENCE OF HOURLY CHANGE RATES AT PARTICULAR HOURS

they encountered a sharp decrease in temperature it is conceivable that they would encounter a larger drop than they had started the day with. Next morning, without having done any more work, a sharply rising temperature might solve their entire problem. Perhaps such things never happen, but it may be useful to investigate the possibilities and probabilities.

At any rate boundary temperatures probably vary in a practicably unpredictable fashion. Whether the variation is important depends on its effect in the determination of aperture area.

Theoretical analysis—In Part I the "air test" equation has been stated to be

$$d = Dn\ (cA/V)t \qquad (33)$$

The "n" in this equation depends on the value of the pressure drop *and* the

change in air temperature during the test. Thus, "n" is largely dependent on heat transfer and it will have the following characteristics in various situations:

(a) if heat transfer *to* the compressed air is sufficiently large n will be *negative* and, therefore, d will be negative, i.e., the pressure will *rise* despite leakage.

(b) a somewhat lesser heat transfer will produce a value of n = o and there will be no pressure drop despite leakage.

(c) a still lesser heat transfer to the air will result in a value of n between zero and unity; the drop will be *less* than that due to leakage alone.

(d) if there is no heat transfer n = 1 and the drop is due solely to leakage.

(e) if the heat transfer is *from* the compressed air n will be greater than unity and the drop will be greater than that due to leakage alone.

A convenient viewpoint to clarify the significance of n is revealed when equation (33) is written

$$n = d/[D(cA/V)t]$$

It will be noted that $D(cA/V)t$ is the drop which would exist if there were no heat transfer and leakage alone were responsible. Therefore, n is the ratio between the actual drop and the "leakage drop."

The important fact is that the value of A cannot be ascertained unless n is known.

The value of n is dependent upon the test pressure, the duration of the test, the surface area and volume of the compartment, the aperture area and coefficient of discharge, and the boundary temperature conditions. All of these factors are widely variable in practice so, probably, the value of n will vary from test to test. In order to get an idea of the probable range of n Appendix I contains calculations intended to show the extreme conditions. The extremes of the various factors have been taken to be

(a) *Compartments*—a small one 8′ x 8′ x 8′ with a volume of 512 cu. ft. and a surface area of 384 sq. ft. giving an S/V = 0.75. A large one of 16′ x 24′ x 60′ having V = 23,040, S = 5,568 and hence S/V = 0.24.

(b) *Period*—all tests are assumed to be for 10 minutes.

(c) *Test pressures*—a low of 1 p.s.i. gauge representing the lower values for completion tests and a high of 10 p.s.i. gage representing the higher pressured strength and tightness tests.

(d) *Apertures*—a small one sufficient to produce a drop of about 0.2 oz. at 1 p.s.i. gage if n were unity and a large one sufficient to produce a drop of 2 ozs. at 10 p.s.i. gage if n were unity.

(e) *Boundary temperatures* — It will be noted from the data on atmospheric temperature changes previously given that during daylight hours (when almost all tests are conducted) the *hourly* change in temperature may be between about +8° and —4°. It must be remembered that the changes in a period less than an hour may be at a greater rate. Thus, the *average* maximum change in 10 minutes will be not less than +8/6 and —4/6 respectively. Merely on the basis of atmospheric changes alone and neglecting the other factors which serve to change boundary temperature it seems not unreasonable to assume that the extremes of "a" would be +0.2°F and —0.2°F and of "m" would be +0.02°F per minute and —0.02°F per minute.

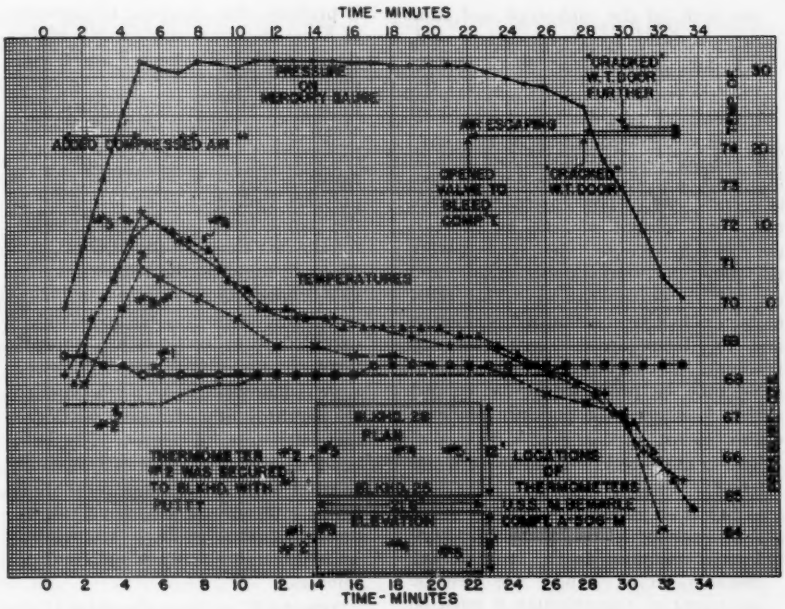
With these conditions the calculated values of n are as shown in the following table.

t	10 mins.							
V	512				23,040			
A	small		large		small		large	
p	1	10	1	10	1	10	1	10
	a = +0.2				m = +0.02			
n	0.4	0.9	1.0	1.2	0.9	1.2	1.2	1.3
	a = 0				m = 0			
n	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3
	a = −0.2				m = −0.02			
n	2.0	1.6	1.4	1.3	1.7	1.5	1.4	1.4

On the basis of these figures it may be inferred that n will vary over a wide range in practice and that the prior implicit assumption that n was unity may have led to large errors in the criticism of compartment tightness. But all the foregoing data have been evolved on the basis of theoretical mathematics and of possibly tenuous assumptions. It is necessary to look for further evidence based on observation.

Practical evidence of heat transfer—The personnel regularly engaged in air testing are very familiar with certain heat transfer phenomena and, though their explanations of causes frequently are incorrect, they are well aware of the effects. One phenomenon of which all test gangs naturally are cognizant is the rapid drop in pressure which occurs immediately after the test pressure is applied initially and the supply of compressed air is stopped. This effect usually is attributed to the deflection of the compartment boundaries, the pressing out of convex buckles in plating or the slow seepage of air into the crevices in faying surfaces, cables, etc. The subsequent intermittent introduction of more compressed air to maintain the test pressure is sometimes called "packing" in the belief that air is a substance like sand which must be "packed" into a space in order to fill it completely.

Actually, the need to "pack" a compartment is due to a heat transfer phenomenon. When compressed air is first admitted to a compartment the original mass of atmospheric air is compressed. In effect, the new compressed air acts as a piston to compress the original mass of air, the temperature of which is thereby increased. Of course the cold air from the compressed air hose mixes with the original air and serves to retard the rise in temperature. The net


TIME - MINUTES
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
"CRACKED" W.T. DOOR FURTHER
AIR ESCAPING
OPENED VALVE TO BLEED COMPT.
"CRACKED" W.T. DOOR
TEMPERATURES
LOCATIONS OF THERMOMETERS
ELEVATION
TIME - MINUTES

final effect, however—despite a widespread and firmly held belief to the contrary—is an increased temperature which, in general, is greater than that of the boundaries. Immediately the introduction of compressed air is stopped, the temperature of the air in the compartment commences to decrease because of the transfer of heat to the boundaries and, as a consequence, the pressure falls. The introduction of more compressed air tends to increase the temperature again and the cycle is repeated. This effect was demonstrated by the tests reported in ref. (d) to determine the length of time required to "stabilize" the test pressure. It was again demonstrated by a test made at the New York Shipbuilding Corporation in which temperatures and pressures were recorded more carefully and completely than in the tests mentioned above. Because the phenomena revealed in these tests are typical of all compartment tests, the latter experiment will be described completely as a matter of interest.

The compartment tested was a magazine. The deck, the overhead, both transverse bulkheads and the port longitudinal bulkhead were insulated with cork slab; the starboard longitudinal bulkhead was not insulated, it being a partition between two magazines. Thermometers were located as shown on the accompanying graph to indicate the following temperatures:

(a) The ambient temperature by thermometer #1 read at intervals of 1 minute.

(b) The temperature of the non-insulated bulkhead by thermometer #2 which was "puttied" to the bulkhead. It was attempted to insulate this thermometer from the ambient atmosphere by carrying the putty well up the stem of the thermometer. Readings were made at 1 minute intervals.

(c) The temperature of the air within the compartment at levels near

the deck, at the mid-point and near the overhead by thermometers #3, #4 and #5. These thermometers were read by an observer within the compartment in the order 3—4—5—4—3 at 30 seconds intervals.

The compartment air test fitting was in bulkhead 25 about opposite to thermometer #4. The pressures were taken at 1 minute intervals by an ordinary mercury gauge. The readings were correlated by stop-watches inside and outside the compartment. The thermometers had been calibrated previously and the temperatures were corrected readings. The temperature determinations may be presumed to be correct within ¼ degree, the pressure readings within ⅛ oz.

The following phenomena are of interest:

(a) The pressure was built up to 2 p.s.i. gauge in the interval between 1 and 5 minutes. In the same period, thermometers 3, 4 and 5 recorded the same *rate* of rise although it must be remembered that with such a rapid rise of temperature the thermometers would "lag" and record something less than the true increase. (Thermometer 5 was not read at the 5 minute point and the reading plotted on the graph is assumed). The indicated rise is about 4¼ degrees.

(b) At 5 minutes the air supply was shut off. The temperature commenced to drop immediately and, of course, the pressure decreased. By 7 minutes the temperature recorded by the thermometers had dropped ¾ degree (considering "lag" the decrease probably was greater) despite the good insulation of the boundaries and the presence of an observer whose body heat of about 200 b.t.u.'s per hour was tending to raise the temperature at a rate in the order of about 0.1 degree per minute. In the same interval, the pressure dropped 1½ ozs. Assuming a "bottle-tight" compartment this drop in pressure would indicate a temperature decrease of some 3 degrees so it is probable that the peak temperature at 5 minutes was considerably higher than recorded. Between 7 and 8 minutes the compartment was "packed" to 2 p.s.i. and the temperature drop seems to have been retarded as would be expected. At 10 minutes the temperature had dropped further and the pressure had again dropped ½ oz. so the compartment again was "packed" for the last time. In the interval from 11 to 22 minutes, the temperature inside dropped about 1 degree as judged by all thermometers and, as would be expected in a "bottle-tight" compartment, the pressure dropped ½ oz.

(c) During the test the ambient temperature first dropped ½ degree and later rose ¼ degree. The bulkhead temperature rose fairly steadily to reach the ambient temperature. The temperature of the air inside was approaching the bulkhead temperature quite steadily between 11 and 22 minutes.

(d) At 22 minutes the valve to the compartment was opened and the temperature inside promptly started to drop. At 28 minutes the W. T. door was "cracked" to accelerate the escape of air and at 30 minutes was "cracked" further. The accelerated drop in pressure after 28 minutes was accompanied, as would be expected, by a more rapid decrease in temperature.

The major significance of the test is the quite rapid transfer of heat from the compartment air to the boundaries during the period from 5 to 22 minutes. Had the compartment not been insulated and had there been no observer inside to radiate heat to the air, the temperature of the air probably would have approached the boundary temperature considerably faster. It is interesting to note that neither the ambient nor the boundary temperature remained constant for appreciable lengths of time despite the fact that the ship was afloat and the compartment concerned was well below the waterline where, if any-

where, constancy of conditions could be expected.

The phenomena described above indicate that when the testing air is at a higher temperature than the boundaries the air will approach the boundary temperature quite quickly. The converse of this question, i.e., when the boundary temperature is higher will the temperature of the air rise quickly, is of equal interest.

It is not extraordinary in compartment testing to encounter an actual rise in pressure even after a compartment has been "packed." This can occur only due to transfer of heat from the boundaries to the air inside the space. Ref. (d) is rich in evidence of this fact. In the tests to determine allowable apertures for various fittings there is reported time after time a "*gain* in ounces" of from ¼ oz. to 2 ozs. in 30 minutes. In every case the "gain" is associated with a rising temperature. Although the test data, unfortunately, does not reveal the location of the thermometer it seems most likely that it was recording ambient conditions. Thus, in these cases, even though the fittings being tested were leaking, the heat transfer of the air within the test tank obscured the fact.

Another set of data recorded in ref. (d) was the result of tests on the "Tank Without Fittings" to determine the tightness of the tank itself. The tank obviously was almost "bottle-tight" as evidenced by the pressure maintained over long periods of time. Therefore, the pressure in the tank rose and fell with the ambient temperature. In fact the tank was acting as the bulb of a huge air thermometer and the changes in pressure probable were more precise indications of the changes in ambient temperature than the thermometer used which obviously was being read only to the nearest degree. It must be remembered, of course, that changes in barometric pressure would affect the height of the mercury gauge, but from hour to hour, the temperature *changes* as indicated by the pressure were better indications of the variations in atmospheric temperature all around the tank than a single mercury thermometer

It cannot be argued that the test tank of ref. (d) is quantitatively representative of practical air test conditions. The tank was relatively small (496 cu. ft.) and, presumably, was isolated from other structure. Nevertheless, the violent disturbance of pressure experienced in ref. (d) probably is a qualitative indication of the experience in practice.

While there is no direct evidence that heat transfer was a disturbing element in the experiments reported in ref. (a) there is certain information to suspect that it played a part. As examples:

(a) The radically different shapes of the curves of coefficients of discharge for circular holes of various sizes. It would seem that the shape of these curves could be expected to be the same in general character, regardless of the area of the hole. The greatly varying character of the curves shown in ref. (a) probably indicates some disturbing influence.

(b) In comments on the allowable aperture values for various fittings, this statement is made: "The results tabulated—are slightly different, in some cases, from those actually derived on test. This is due to the necessary fairing up of results." It is possible that the necessity to fair up results arose from other causes than observational errors.

Air test personnel sometimes state that sunny days are "good" for air testing, cloudy and, particularly, rainy days are "bad." It is considered more difficult to get a compartment tight on a rainy day. If heat transfer is a factor in the problem this is a logical statement because on rainy days the atmospheric temperature does not rise anywhere near as rapidly as on bright days and the absence of solar radiation would promote steadier boundary temperatures. In this connection the following data is interesting. CL55 and CV22 were con-

structed at the New York Shipyard approximately at the same time. Both ships are generally of the same type of construction inasmuch as CV22 was started as a sister ship of the CL55 and was changed to a carrier after construction was well along. The CL55 was built on covered ways, the CV22 on open ways exposed to the sun. The air test data for strength and tightness tests conducted prior to launching is compared in the following table. In order to eliminate the effect of varying test pressures the value of nA/V for each of the compartments studied was calculated. Theoretically, the value of A/V for a given compartment will remain about constant regardless of the test pressure and, therefore, its value (which might be termed "tightness per cu. ft.") is an "index" of tightness. The average value of A/V for a large number of compartments gives the "degree" of tightness which prevails. It might be expected that, for a number of voids or storerooms or living spaces on a given ship, the average of A/V would be about the same for a sister ship and, as will be shown later, the results of many tests indicate this to be the case. Therefore, if n varies materially between two ships it might be expected that a comparison of nA/V would indicate this fact. Such a comparison showing the number of compartments in various ranges of nA/V values follows:

No. Compartments in Various $n\frac{A}{V}$ "Brackets"

Test Pressure	CL55—Covered Ways							CV22—Open Ways						
	0	1-4	5-8	9-12	13-16	17-20	>20	0	1-4	5-8	9-12	13-16	17-20	>20
	Voids													
0–2	1							28			3			
>2–5	3							2				1		
>5–8	1		5	8										
>8–11	1		1	3		3		1						
>11–14	1				1	1		9	4	2	2		1	
Total	7		6	11	1	4		40	4	2	5	1	1	
%	24		21	38	3	14		75	8	4	9	2	2	
	Stores													
0–2	4						1	11			3	2		
>2–5	8		3	1	1			5				2		
>5–8	3			2			2							
>8–11	1		1	1				1			1			
Total	16		4	4	1		3	17			4	4		
%	57		14	14	4		11	68			16	16		
	Magazines													
0–2								4			1	2		1
>2–5	1		1					1						
>5–8	2		18	6			1	9		2	5	3		
>8–11	1		1	1		1	2			1	1			
Total	4		20	7		1	3	14		3	7	5		1
%	11		57	20		3	9	47		10	23	17		3
Grand Total	27		30	22	2	5	6	71	4	5	16	10	1	1
%	29		33	24	2	5	7	66	4	4	15	9	1	1

The *average* values of nA/V for the two ships is about as follows:

	CL55	*CV22*
Voids	8.5	2.4
Stores	5.6	4.3
Magazines	8.3	6.5
Total	7.6	4.0

It may be argued that on CV22 the large number of tests conducted at low pressures gives an undue weight to that ship but a comparison of all tests conducted at pressures greater than 5 p.s.i. shows *average* values of nA/V to be:

	CL55	*CV22*
Voids	9.8	3.6
Stores	8.5	5.5
Magazines	8.5	6.2
Total	9.0	5.0

It is possible that the average of n for the two ships was the same and that the average A/V was smaller on CV22 for one or more of the following reasons:

(a) more rigid inspection. (This seems unlikely.)

(b) more careful workmanship. (This seems unlikely.)

(c) the greater degree of corrosion due to the unprotected structure. (This is entirely possible, although the steel for both vessels was pickled and given a priming coat of paint prior to erection, a process which should have retarded corrosion materially.)

If none of these factors explains the lower average nA/V value on CV22 then the answer lies in a lower value of n due to heat transfer. It is interesting to note that the greatest disparity occurs in Voids which, being closer to the shell, would probably get the greatest effect of solar radiation.

It would appear that there is sufficient theoretical, practical and experimental evidence to suspect that heat transfer has been a major disturbing influence on the accuracy with which compartment tightness has been determined in the past.

Probable values of n which occur in practice—There appears to be practically no observed data on which to base sound estimates of the probable values of n encountered in practice. The practical evidence presented above is qualitative only. The following data are flimsy foundations for conclusions but they are presented for what they are worth.

The data in ref. (d) can be considered nothing more than very rough approximations of practical test conditions but its clues are worthy of some notice. From the tests on leakage through small circular holes, the values of n can be determined from the equation

$$d = Dn(cA/V)t\,[1 - E(cA/V)t]$$

For lack of better information, it may be assumed that the values of c were the "mean" values given in ref. (a). The results are:

VALUES OF N

Diam. Hole	Test Pressure (p.s.i. gauge)								
	¼	½	1	2	3	4	5	10	15
1/64"	–1.7*	–1.8*	–0.9*	–0.6*	–0.3*	–0.2*	–0.2*	1.0*	0.8*
1/32"	0.7*	1.2	1.1	1.5	1.3	1.5	1.5	1.4	1.5
1/16"	0.7	1.0	0.9	1.1	1.1	1.1	1.2	1.1	1.3
3/32"	0.5	0.6	0.8	1.0	1.0	1.0	1.0	1.0	1.0
1/8"	*1.3*	0.5	1.0	1.2	1.2	1.2	1.2	1.2	1.2

All 30 minute observations except: *60 mins. *. 15 min.

These results, of course, are valid only for the particular tank involved and for the particular conditions which prevailed. Furthermore, they are highly approximate because the drops were measured with insufficient precision and because of ignorance of the correct values of c. It should be noted that as the aperture area and the pressure increase, the variability seems to decrease as would be theoretically the case. At least these data are indications that the order of magnitude of the theoretical predictions of n are about correct.

The data on average values of nA/V for the CL55 and the CV22 as given above offer a faint clue. First assume that for all the compartments tested the general average A/V for each ship was the same and that the difference in average nA/V was due to a different average value of n for the two ships. Now assume that the CL55, having been tested on a covered way, had an average n of unity. The average value of n for the CV22 would be

(a) when all compartments are considered, $4.0/7.6 = 0.53$

(b) for tests over 5 p.s.i. $5.0/9.0 = 0.56$

If this same scheme is applied to the groups of compartments of the various types, the results would be:

Voids

$2.4/8.5 = 0.28$ or $3.6/9.8 = 0.37$

Stores

$4.3/5.6 = 0.77$ or $5.5/8.5 = 0.65$

Magazines

$6.5/8.3 = 0.78$ or $6.2/8.5 = 0.73$

These data represent *average* conditions and do not reveal the extremes which occurred in the tests of the individual compartments. If the analysis is a reasonable one it is evidence that the ship which was exposed to solar radiation encountered generally much lower values of n than did the sheltered ship, as would be expected.

The foregoing data, poor as they are, seem to confirm in some degree the theoretical analysis summarized previously. Those results are based on what appear to be conservative assumptions. They indicate that n may vary in small compartments between 0.4 and 2.0 and in large compartments between 0.9 and 1.7. It is possible, even likely, that the range in practice is wider. In any case it is reasonable to conclude that n will be unity in but few cases.

The remainder of this article, consisting of three sections and two appendices, will be published in subsequent issues of the JOURNAL.

WAVE DRAG OF SHIPS

EDITOR'S NOTE

In the August 1951 issue of the JOURNAL was carried an article written by Max Otto Kramer entitled "The Wave Drag of Ships." This was followed by an interesting series of letters which was initiated by Mr. M. St. Denis, an eminent naval architect at the David Taylor Model Basin. In the interest of correcting an error, if such has been made, and certainly for the purpose of wider dissemination of information on the subject, the letters mentioned above are published below, followed by a reprint of the article which was referred to in Mr. St. Denis' first letter.

NAVY DEPARTMENT

DAVID TAYLOR MODEL BASIN

WASHINGTON 7, D. C.

December 20, 1951

Captain J. E. Hamilton
Secretary-Treasurer
The American Society of
Naval Engineers
605 F Street, Northwest
Washington 4, D. C.

Dear Captain Hamilton:

I have read with some concern the paper by Max Otto Kramer on the Wave Drag of Ships published in the August issue of the JOURNAL. My first reaction is a surprise that a man of the reputation of Dr. Kramer should make such far-sweeping but absolutely false generalizations as appear in his article. To be specific, I refer to the statements that "the literature on wave drag of ships offers nothing but empirical formulas, whereas the theoretical solution of the problem is considered hopelessly complex" and that "no theoretical expression for the wave drag of ships has been derived which agrees with actual measurements." Nothing could be farther from the truth!

For substantiation of this assertion, I should like to refer you to a recent article by Dr. George Weinblum titled, "The Practical Use of Theoretical Studies in Wave Resistance" and published in the *October issue of Marine Engineering and Shipping Review*. You will find in Fig. 3 of the article evidence that wave resistance can be calculated much more closely than the 40% which Dr. Kramer claims for his method.

I do hope for the prestige of the JOURNAL that the Editor will be less impetuous in printing such articles in the future.

Sincerely,

M. St. Denis.

January 9, 1952

Mr. M. St. Denis,
David Taylor Model Basin
Washington 7, D. C.

Dear Mr. St. Denis:

Thank you for your letter of 20 December, 1951. I have mentioned its receipt in the forthcoming February, 1952 issue of the JOURNAL. Time will not permit fuller treatment in that issue.

I am sending a copy of your letter to Dr. Kramer for any comment which he cares to make. The two letters, or pertinent extracts from them, along with Dr. Weinblum's paper (if we can get permission to reprint), will be carried in the May, 1952, issue. I should also be glad to include anything further which you may want to send in.

Sincerely,
J. E. Hamilton,
Secretary-Treasurer.

From: Dr. Max Kramer
Naval Air Development Center
Johnsville, Pa.

15 February 1952

To: Mr. St. Denis
Navy Department
David Taylor Model Basin, Washington 7, D. C.

Dear Mr. St. Denis:

Captain Hamilton sent me your letter two weeks ago and I managed to get the article of Dr. Weinblum one week ago. Thus I would like to discuss the matter with you in order to come to some agreement and eventually to get your help in checking my formula.

I wanted to derive a simple formula showing the basic correlation of the wave drag and the principal dimensions of a ship. The article of Dr. Weinblum does not give me the impression that this formula already exists. The wave drag theory is elaborate but apparently does not arrive at simple and general conclusions or else Dr. Weinblum would have mentioned them. Michell's resistance formula may be very valuable in certain ranges but it combines wave drag and friction drag. Both drags add up and each of them follows different exponents of the principal dimensions. As you know it means violating mathematical laws to express such a sum by a single product. Thus this formula can be valid only in a limited range or correction tables are needed whereby the simplicity and physical clarity are lost. The rest of Dr. Weinblum's article compares special theoretical conclusions with practical results. Though certainly very valuable in particular, this part of his article does not help to clarify the over-all picture.

When I derived my formula I knew I was making approximations and I said so. Naturally I wanted and still want to know how well this approximation can summarize the results of vastly different applications. My article mentions the checking range from battleship to destroyer. Actually I expanded this range to skiffs and kajacks and, there too, found my formula verified within the scatter that

has to be accepted when important factors, such as the propulsive efficiency, the actual draft, and the actual contour are replaced by average values. The range I actually checked was 1 to 10^6 in displacement, 1 to 6 in speed and 1 to 5 in slenderness.

I think you must admit that if a simple theoretical formula *with no empirical factors attached,* covers this tremendous range without systematic deviation, the basic concept of this formula must have its point. In case further checks convince me fully I can easily improve my formula by taking the missing factors into account and thereby cutting down the "local" scatter.

You could greatly assist me by sending me official Model Basin results on bodies similar to the three-dimensional body shown in my article. I hope you will do so.

Sincerely yours,

K.

NAVY DEPARTMENT

DAVID TAYLOR MODEL BASIN

WASHINGTON 7, D. C.

10 March 1952

Dr. Max Kramer
Naval Air Development Center
Johnsville, Pennsylvania

Dear Dr. Kramer:

I have just returned from an extended trip abroad and for this reason I have not been able to reply to your letter of 15 February before now. To comply with your request, I am sending you two Model Basin reports (No. 710 and 758), both by Dr. Weinblum, bearing on the subject of wave resistance. These reports give an exposition of the theoretical approach. I would like to refer you to an additional article by Weinblum, Amstberg and Bock titled "Versuche ueber der Wellenwiderstand Getauchter Rotationskoerper" published by the Preussischen Versuchsanstalt fuer Wasserbau und Schiffbau, Berlin, 1936, which gives some experimental results. The bibliography listed in the first report will give you an idea of the extensive work that has been carried out already on the subject. Of especial importance in connection with possible practical application to ship design are the contributions by Havelock and Wigley to the Institution of Naval Architects in London. (Items 76, 77, and 89 of the bibliography TBM report 710.)

In my opinion your attempt to find a simple formula for the wave-making resistance of ships is bound to be fruitless. The reason for this statement is that the wave-making resistance of a vessel is essentially a function of the slopes (derivatives) of the vessel's wetted surface. This surface cannot in general be expressed by a small number of simple parameters and, consequently, neither can the slopes. Your proposal to use only a vessel's principal dimensions is, therefore, unsound in principle.

Nor will the quest for missing factors help any. There are too many such to be taken into account. For example, even if we retain unaltered a design's principal dimensions and primary coefficients, we can still obtain extremely wide variations in

wave-making resistance by operating on the secondary coefficients alone as, e.g., by altering the longitudinal (or vertical) distribution of displacement, but not the longitudinal (or vertical) center of buoyancy; or by altering the waterplane inertia, but not its area, etc. It would be extremely difficult to account for all such possible variations in a simple formula.

In your letter you state that yours is a simple theoretical formula with no empirical factors attached. I must disagree with this statement. The factor $C = 4.5$ is purely empirical. It is a fortuitous coincidence that for actual vessels it has a value somewhere near a mean value derived for two- and three-dimensional forms having a specific profile.

I also must disagree with your statement that Michell's formula combines wave drag and frictional drag—Michell's theory is based on the assumption of potential flow (i.e., of an ideal inviscid fluid). Indeed corrections have been worked out to allow for the effect of viscosity on the potential, wave-making resistance, as you will find in Wigley's paper referred to above, but these do not affect the frictional resistance which, according to Froude's hypothesis, is calculated separately.

I do hope that the reports I am enclosing and the papers I have referred to in this letter will provide you with interesting reading on this fascinating subject of the wave-making resistance of ships.

Sincerely yours,

M. St. Denis.

THE PRACTICAL USE OF THEORETICAL STUDIES IN WAVE RESISTANCE

ACKNOWLEDGMENT

DR. GEORG P. WEINBLUM, a consultant at the David Taylor Model Basin, is the author of this article which was published in the October 1951 issue of "Marine Engineering and Shipping Review." This article is of particular interest because its approach to the problem is different from that outlined in the paper "The Wave Drag of Ships," by Mr. Max Otto Kramer, published in the August 1951 edition of the JOURNAL.

The analytical treatment of wave resistance of ships' forms is an important part of modern theoretical naval architecture. The Society of Naval Architects and Marine Engineers has acknowledged this fact by creating recently a "Wave Panel," the main objective of which is the speculative study of ship resistance. Therefore, it is thought that a short review on the subject may present some interest.

In what follows it is assumed that the reader is to some extent familiar with D. W. Taylor's book *Speed and Power of Ships* or with Davidson's chapter on "Resistance and Powering" in *Principles of Naval Architecture,* Volume II.

The ties between mathematics—especially its applied branch of theoretical hydrodynamics—and shipbuilding practice have not been equally close over the centuries. The work of Archimedes, one of the greatest mathematicians of all times, was inspired profoundly by problems of naval architecture, but nearly two thousand years passed by before his famous law and his powerful investigations on stability began to be applied by our profession.

During the eighteenth and nineteenth centuries, naval architecture contributed appreciably in a direct and an indirect way to the development of classical hydrodynamics. On the other hand naval architects were eager to make use of scientific results, as can be seen from the older volumes of the *Transactions* of the Institution of Naval Architects in London.

However, with the rise of airplane building the interest of hydrodynamicists shifted more to the field of aerodynamics. At the same time it became fashionable with practical people in our profession to question the practical value of that part of hydrodynamics which is based on the concept of an "ideal" frictionless fluid. A familiar stumbling block was d'Alembert's famous paradox, according to which a body moving rectilinearly with constant speed in a frictionless liquid does not experience any resistance. Such a tendency to neglect admittedly abstract studies had a deplorable effect; it lowered the standard of the dignified theoretical naval architecture and reduced further the interest of mathematicians

and physicists in problems of our profession. Fortunately this state of affairs has been overcome; classical hydrodynamics is now recognized as an indispensable foundation of ship-resistance theory. This applies especially to the important problem of wave resistance where distinguished achievements have been reached—among others by Sir Thomas Havelock whom we venerate as the greatest living scientist in our profession.

In what follows we shall give a short summary as to how far the rather complicated theory involved has contributed to our useful knowledge on this subject and may influence the future development of ship forms.

SHIP RESISTANCE

To explain the origin of wave resistance we state first that d'Alembert's paradox in the form quoted in the foregoing is correct only when we deal with the motion of a body far away from a free surface. As soon as the body advances close to the latter, a resistance arises due to the formation of the familiar gravity waves; the laws governing these can be established with reasonable accuracy using the fiction of a frictionless fluid.

It is well known that an elaborate experimental-model technique, due mainly to W. Froude, has been developed essentially with the purpose of investigating wave resistance. The most valuable systematic work done in this field is that of Admiral D. W. Taylor; the diagrams in his famous book *Speed and Power of Ships* are still the best source of general information for the designer.

Is there from a purely practical point of view any need to consider theoretical studies on the subject?

To give an answer to this question some remarks must be made on ship resistance in general. Our present classification of "components" of the total resistance R_t is slightly different from the earlier one found in most textbooks, as has been pointed out in reference [3].*

Neglecting the air resistance, we distinguish:

1. The frictional or tangential resistance R_f,
2. the viscous normal or pressure resistance R_p,
3. the wave resistance R_w, and
4. the spray resistance R_s.

W. Froude introduced the artificial concept of a residual resistance R_r as the difference of total resistance minus frictional resistance of the equivalent plate having the same wetted surface and length as the ship R_{of}

$$R_r = R_t - R_{of} \qquad (1)$$

This residual resistance includes a number of heterogeneous elements:

1. The wave resistance R_w,
2. the viscous pressure resistance R_p,
3. the frictional form resistance

$$R_{fF} = R_f - R_{of} \qquad (2)$$

(since it is obvious and well proven that the frictional resistance of bodies must be different, in principle, from and both lead to identical results. There are further

4. the spray resistance R_s.

Thus

$$R_r = R_w + R_p + R_{fF} + R_s \qquad (3)$$

The most important problem of roughness effects can be left outside of the present discussion.

It follows immediately that the wave resistance R_w is only one part of the

* Numbers in brackets indicate references listed at the end of this article.

residual resistance R_r; in *principle* the present model technique does not yield, at least immediately, the magnitude of the wave resistance. Further, in the low-speed range the model technique itself presents serious difficulties which are being overcome only at present.

Therefore, we conclude: Although from a physical point of view some objections can be made against the splitting up of the total resistance into various components, since they are really interdependent, it is indispensable to conduct separate investigations on these components. This applies especially to the wave resistance because of its importance in general and because of its sensitivity to changes in the ship form. We are fortunate to have hydrodynamic theory as a powerful tool of research in this field.

Some tendencies now exist to overemphasize the difficulties experienced in model testing. The writer does not share them. Having stated these difficulties in *principle* it must be added that fortunately under many conditions the wave resistance can be derived reasonably well from the residual resistance. This fact makes checks possible between theoretical and experimental data.

CALCULATION OF WAVE RESISTANCE

The wave resistance experienced by a moving ship is due to the generation of the wave pattern which travels with the ship. Usually it consists of the well-known divergent and transverse wave system. Knowing the pattern, the resistance can be calculated in principle by two methods:

1. By summing up the pressure forces due to the waves around the hull.

2. By calculating the energy left in the waves behind the ship.

Both ways of approach are physically well founded and both lead to identical results. There are further powerful methods for calculating the wave resistance but they are physically less evident. Since this synopsis is concerned more with the results obtained than with the procedures which lead to the results, we can confine ourselves to these brief remarks.

The method based on pressure computations appeals best to the engineer. Theory as well as experiment can furnish the shape of the wave profile around the ship. It seems to be natural to derive from these wave profiles the pressure changes and finally the wave resistance.

It should be cautioned, however, that the connection between surface wave profiles and pressure changes around the hull is not simple [4]. Further, the calculating of the resistance from positive and negative elements of comparable degree of magnitude and known only to a limited degree of accuracy can lead to serious errors. Thus, former attempts to base wave-resistance calculations on measured model wave profiles were not too successful and only recently improvements have been made [4].

The theoretical process used is not subject to this criticism, although other difficulties arise. The final expressions of R_w are rather complicated integrals, the evaluation of which requires a tedious amount of numerical work.

The existing theories are based on assumptions which limit to some extent the practical applicability of results. Common to them is the assumption of an ideal frictionless liquid and of small steepness of the waves generated. Further, it is impossible to calculate the resistance of an actual ship hull, al-

though hydrodynamics has developed two concepts which admit of approximating ship forms in such a way that its essential features can be pictured. In doing so, additional factors must be neglected, however.

The first idea consists in replacing the ship form by a pressure system distributed over the free surface; it was originally proposed by Kelvin [5] and developed by Hogner [6]. The wave pattern due to the moving single pressure point exhibits the most salient features of a ship-wave system; it is reproduced here (Fig. 1) in the form derived by Hogner, who corrected some errors—still found in textbooks—in the original picture given by Kelvin. From physical reasoning it is plausible that by a pressure system distributed over the surface certain vessels, preferably of shallow draft, can be approximated; in fact, this method proves to be useful in studies of planing vessels but its application to surface ships meets difficulties. The most essential one consists in finding a pressure distribution for a given ship form. In older textbooks some rather confused statements can be found on the wave pattern created by a ship based on the oversimplified representation of the ship by two pressure points. Although some general features of the phenomenon involved can be described in such a way, it is advisable to rely on more advanced information due to Havelock and Wigley [7] [8]. The same applies to the concept of wave-making length or length of separation which has been popular in earlier publications; its value is doubtful since even the definition is rather arbitrary, though some basic effects can be qualitatively explained by it.

The second method is based on the concept of source and sinks introduced by Rankine. Its great advantage is the high generality which leads to useful applications in many fields of theoretical naval architecture. Again there are

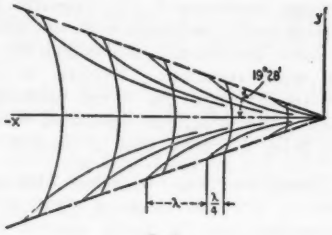


Fig. 1

difficulties to find source-sink distributions corresponding to given hull forms, but in two cases reasonably simple dependencies can be found:

1. For a submerged body of revolution.

2. For a "thin surface ship" (see Fig. 2).

The latter is characterized by small slopes between the surface and the longitudinal center plane; this again involves that for normal ship forms the ratio L/B must be large and the ratio B/H moderately small. Such an extreme ship form is called Michell's ship since Michell [9] succeeded in giving a resistance formula for this type of surface vessel on which most contemporary studies of wave resistance are based.

We face the following dilemma; because of its limitations the existing theory needs experimental checks, while at the same time the common testing routine does not yield reliable data for the wave resistance in the low speed range.

It is fortunate enough that notwithstanding these difficulties the agreement between calculated and experimental data is on the average reasonably good.

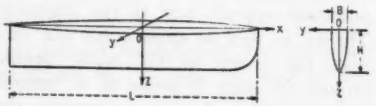


Fig. 2

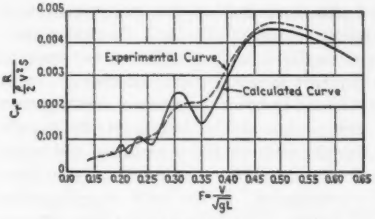


Fig. 3

An example taken from [10] is shown in Fig. 3. Our contemporary state of knowledge indicates that a combined theoretical and experimental approach to our problems is indispensable.

Michell's integral (resistance formula) can be symbolically written as

$$R = \rho g \frac{B^2 H^2}{L} E\,[H/L, \eta, F] \;..\; (4)$$

where ρg is the specific weight of the water; L, B, H are the principal dimensions, η is a dimensionless equation of the wetted hull surface or in plain language η represents the dimensionalized offsets of the hull used by all naval architects.

$$F = \frac{V}{\sqrt{gL}}$$

is the Froude number where V, g, L must be given in consistent units. F is numerically equal to 0.297 times the more familiar speed length ratio VKn/L'.

The symbol E [H/L, η, F] indicates that the resistance depends in some complicated way upon the H/L ratio, upon the dimensionless offsets and most decisively upon the Froude number or speed.

SOME CONTRIBUTIONS OF THEORY TO OUR KNOWLEDGE OF WAVE RESISTANCE

We summarize now the most important results derived from theory. This part of our study relies heavily on reference [3].

1. From the theory of wave resistance it follows that the only appropriate dimensionless speed value for normal-displacement ships is the Froude number $F = V/\sqrt{gL}$ referred to the ship length L.

2. From equation (4) the wave resistance is proportional to the square of the beam $R \sim B^2$. Actually, this holds for narrow ("thin"), wedgelike ships only where L/B is very large. For common L/B ratio an exponent less than 2 is in better agreement with experimental data which, however, are astonishingly scarce [3].

3. Following equation (4) the dependence upon draft is more complicated. Computations show that at high Froude numbers, for instance for destroyer conditions the resistance is proportional to a power of H slightly below the second, while for slow ships it can become proportional to a power less than one [3]. Again, only a small number of theoretical evaluations have been made so far and reliable experimental data are scarce. It follows further from theory that almost the sole effect of changing draft is to change the magnitude of the resistance curve—not its shape.

4. The oscillatory character of wave-resistance curves derived from experiments is well known; the waviness of calculated curves is still more pronounced.

There are two main methods of representing results; the one shows the resistance R itself or D. W. Taylor's resistance-per-ton coefficient R/Δ; the other shows coefficients referred to the square of the velocity of the type

$$C_R = \frac{R}{\rho/2\, V^2 S}$$

or

$$C_V = \frac{R}{\rho/2\ V^2 {}_V{}^{2/3}}$$

where S is the wetted surface and V the volume. The independent variable (abscissa) is $F = V/\sqrt{gL}$.

The position of the maxima and minima in the C_R (or C_V curves and in the R (or R/Δ) curves obviously cannot coincide. This applies especially to the large final hump. The absolute maximum of the wave resistance occurs not too far from $F \cong 0.7$, while the maximum of the coefficient C_R lies close to $F \cong 0.50$.

5. At very high speeds the wave resistance R decreases—although rather slowly—and finally disappears for an infinitely large Froude number.

6. Following theory, ships of least wave resistance must be symmetrical with respect to the midship section. This result may be stated in a somewhat different way as follows: assume a displacement distribution symmetric with respect to the midship section. Any change in this distribution leads to an increase in resistance provided the arithmetical mean of the fore and afterbody distribution remains equal to the original one. Further, it follows from theory that the resistance of ships asymmetrical with respect to the midship section is the same if run bow first or stern first.

These results do not agree with facts since the influence of the change of trim and of viscosity have been neglected by theory. Some remarks on the subject will be made later.

7. The shape of the resistance curve, especially the position of the humps and hollows and its relative magnitude, depends primarily upon the longitudinal distribution of displacement. The prominent importance of the sectional-area curve is emphasized by theory.

An increase of the prismatic coefficient C_P or of Taylor's tangent value t generally causes a shift of the maxima towards larger Froude numbers. The influence of other important form parameters, such as the length of the parallel middle ship or the amount of curvature at the midship section, has also been investigated. From such investigations it follows that large variations in wave resistance may correspond to small changes in the longitudinal displacement distribution. The sensitivity of resistance to changes in form varies with the range of the Froude number.

This is a most important result. It explains the complete failure of numerous attempts to express the resistance as a function of simple coefficients; it explains further why experimentation based on single models—or even on a systematic series not guided by theoretical considerations—cannot yield results capable of wider generalization.

8. Theory has produced a satisfactory explanation for the problem of the bulbous bow and, in this case, it even furnishes some quantitative resistance data.

9. The longitudinal distribution of displacement which leads to ship forms of least wave resistance has been calculated and good agreement with earlier experiments due to D. W. Taylor has been found [3]. The optimum forms vary decisively with the Froude number, a fact which has been overlooked by many inventors.

10. Theory provides a rather obvious rule how to distribute the displacement in the vertical direction: From the point of view of wave resistance it is advantageous to shift the displacement as far as possible down below the free surface. Thus in this respect U-shaped sections generally are preferable to V-shaped sections.

11. We previously mentioned under Paragraph 6 erroneous conclusions de-

rived from theory which are caused by neglects of viscosity effects. Closer agreement with well-established facts can be arrived at by introducing semi-empirical corrections [11] [12]. However, this procedure, although useful, is not yet quite satisfactory from a scientific point of view.

12. The wave resistance of wholly submerged bodies of revolution moving close to the surface can be calculated in a similar and even simpler way than for surface ships.

A lot of calculated resistance results are in the process of publication [13]; they show some rather surprising dependencies upon the form.

13. Theory has furnished reliable methods of calculating the wave resistance of ships moving in shallow water and in rectangular canals. Because of the limited space, this theory [3] cannot be expanded here.

14. Many endeavors have been made to develop new types of craft which have no appreciable wave resistance. It is not difficult to give some broad answers to the question involved: With respect to speed variation, low wave-resistance is obtained when the Froude number is very small or very large; the latter condition is realized by high-speed planing vessels and hydrofoils. Another way also attempted by inventors is to submerge the vessel; this procedure works, however, in the range of moderate and moderately high Froude numbers only when the ratio depth of immersion f to the length of the vessel L is not too small. Quantitative information on this latter subject can be easily derived from existing data [13].

15. A successful attempt has been made by Dickmann to calculate the wave resistance created by a screw propeller and the interaction between the ship and the propeller wave system [14]. He has shown that the wave resistance of the propeller itself is normally very small, but that the interference effects between the propeller and ship can nevertheless become appreciable.

SUMMARY

Summarizing we state: Theory has given a broad picture of the wave resistance phenomena over the whole speed range. It has indicated the sensitivity of resistance to small changes of form in some speed ranges and thus given a useful guidance to model technique. Calculated resistance curves for a large variety of normal ship forms will soon be available. The quantitative agreement between calculated and measured resistance data is reasonably good under certain conditions, but should not be overemphasized. Theory fails to give correct values for full ship forms at low speeds. Although much is left to be done on the influence of the actual proportions of the ship and still more of viscosity effects on wave resistance, theory proves to be an indispensable tool of research and it is expected to become a valuable help in design.

A rather comprehensive list of references can be found in reference [3]. The present list does not acknowledge properly, among others, the decisive contributions made by Havelock and Wigley in this field.

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METAL ECONOMICS

ACKNOWLEDGMENT

This is an abridged report of a discussion held at a meeting of The Institute of Metals in London on 17 October 1951. It is reprinted from the "Journal of the Institute of Metals" of January 1952. Because of its length only Part I is being reprinted at this time.

I.—Primary Resources of Ferrous and Non-Ferrous Metals

BY PROFESSOR A. J. MURPHY,* M.SC.

INTRODUCTION

In the discussion today, we shall doubtless find that more than one speaker will refer to the short-term and the long-term problems of supply and demand, and it would be difficult to deny the justice of this distinction. In the short-term, say during the next three years, the problem of ensuring a balance between supply and demand is easier in some respects, and more difficult in others, than when the long-term prospect is being considered. It is easier in the sense that emergency measures can be taken, for instance by raiding stocks intended to cater for forward requirements, by using highly uneconomic methods of mining and refining metals, or by denying supplies for applications which can be deferred for a time though not indefinitely—all of these are means which would have no relevance to a long-term policy. On the other hand, time, money, and men are the great obstacles when a quick, though temporary, alleviation has to be found. The limitation of time is especially intractable when the expansion of supply depends upon the construction of new plant and buildings, for instance, for electrical generating plant for the production of aluminum or magnesium from minerals which are plentiful. Money in the form of investment capital is not readily attracted to mines and factories which are to be developed rapidly for a current demand without a firm prospect of commercial success in the more distant future. Finally, the operative labor and skilled technicians must be drawn from an industry already claiming to be inadequately staffed.

In war all these difficulties are swept

* Professor of Industrial Metallurgy, University of Birmingham.

aside by the sheer necessity for survival. In the phase of peacetime rearmament in which we are now it is not possible to concentrate all effort on the simple objectives of providing the military machine with its needs and keeping the civilian population alive; a triple balance has to be maintained between immediate service requirements, building up reserves for security if war comes, and the supplies needed for civilian trade, especially for export.

In my Presidential Address I referred to the three significant elements in the balance between supply and demand as: (1) the increasing population of the world, (2) the non-renewable character of mineral resources, and (3) the world-wide demand for higher standards of living. Statistics in plenty are available to show that, while the world population is rising by about 1% annually, the consumption of metals is swinging upwards at a much higher rate.

It is self-evident that if these rapidly accelerating inroads into a fixed amount of resources were to continue indefinitely the final exhaustion of metal supplies would be inevitable. The two vital questions are: what quantity of workable resources remains untapped and what are the prospects of the rate of winning metals from the earth (and the sea) keeping pace with the soaring demands? Here we find a cleavage of opinion among those who have studied these questions, and no doubt we shall be made aware of these differences as the meeting proceeds.

Those who find grounds for believing that critical and enduring shortages will be experienced within a generation consider that, among our present common metals, lead, zinc, and copper are destined to move into the category of relatively scarce commodities. At the other end of the scale, iron, aluminum, magnesium, and perhaps titanium are expected to remain plentiful for a much longer period.

Opponents of the view that we are within sight of the exhaustion of some of our staple metals point to the fact that in the past under the stimulus of growing demand the requisite increase in supplies of metals has always been forthcoming. They express the faith that in a free economy and given normal peacetime conditions the ordinary price mechanism will provide the incentive for mineral exploration and the exploitation of new sources and improved processes. The point has been well made in this connection that a more powerful stimulus than a high price for the mined product is an assured continuing demand.

I am sure that many other metallurgists will share my feeling of pleasure that in giving consideration to these matters today we have the benefit of the opinions of economists and of geologists. They will not need to be reminded how vitally important it is to metallurgical industry to arrive at a sound appraisal of the forces influencing the future trend of supply and demand of the basic metals. To take only three examples, we may mention galvanizing, copper for high-tension transmission lines, and lead in electrical accumulator batteries. Is the stringency in supplies of zinc likely to remain so severe, even when the needs of rearmament have been met, that alternative means of protecting steel will replace galvanizing permanently in many applications? Will a continuing critical shortage of copper lead to a large extension of the use of aluminum for overhead conductors? Will the depletion of lead resources cause the lead accumulator to be replaced by other types embodying other, more plentiful, metals?

An affirmative answer to any of these questions will imply as a consequence a change in production methods which may range from a simple adaptation of existing plant in one case to a complete upheaval in another, demanding the learning of new techniques of manufac-

ture, control, and even of selling. For the metallurgist in industry the need for versatility and adaptability to cope with the new situation is obvious, but there is another phase of metallurgical activity in which it is important to have, as early as possible, guidance on the future trend of supplies. I refer to the work of the research metallurgist. In this country, with our limited resources of technical manpower and equipment, it is especially important that a substantial part of these resources should be engaged in the most useful and effective way, in relation to national needs. If we can know now that supplies of metal *B* will be plentiful while those of metal *A* will inevitably diminish, we can direct an intensified program of metallurgical research to a study of metal *B*, and especially of its alloys.

This is not a matter which calls for help only from the technical metallurgist: the theoretical metallurgist must also be ready to commit himself to forecast technically useful compositions and treatments of unfamiliar alloys which are likely to be available when the better-known materials have become unobtainable.

Economic considerations and technical metallurgical factors are closely linked in almost every aspect of this subject. Others, more expert, will develop this theme, and I shall only refer briefly to two points. The first is the changed situation in the metal industry when scarcity pushes the price of a basic metal much higher relatively to the other main components in the cost structure of the product. Many visitors to America have described how the metal-working industry there has been built up on the acceptance of labor as a relatively scarce and costly commodity, expensive plant being installed to make the most economical use of human labor, and production schedules then being planned to keep the plant working at full output with the least possible interruption. If now a section of the industry has to reconcile itself permanently to a greatly enhanced cost of its raw material, it may be compelled to change this philosophy. In such new circumstances the most important requirement would be to eliminate every cause of wastage of metal, and expenditure on plant and labor would diminish in significance. It would mean that the attitude of industry towards its metals would shift away from that of the mass-production iron foundry and steel mill towards that of gold-mine and the silversmith.

As I have remarked previously, the problem can be expressed in the form of three questions:

(1) What can we do to improve our supplies?

(2) How can we make better use of what we have?

(3) What substitutes can we use in place of the metals which have become difficult in supply?

The first question will fall for consideration in Part I of this discussion; the other two questions in Part II.

The World Supply of Non-Ferrous Metals, Including the Light Metals

BY R. LEWIS STUBBS*

I am going to talk about copper, zinc, lead, tin, aluminum, and magnesium, and I shall try to assemble the facts on which any forecast of supply and consumption must be made.

* The British Non-Ferrous Smelters' Association.

TABLE I.—*World Production and Consumption of Copper, Zinc, Lead, Aluminum, and Tin, 1948–50.*

(Thousands of metric tons)

		1948	1949	1950
Copper	Refinery production	2291	2237	2537
	Consumption	2326	2075	2539
	U.S. Special Account purchases	13	163	208
Zinc	Smelter production	1564	1680	1819
	Consumption	1543	1478	1847
	U.S. Special Account purchases	54	103	115
Lead	Smelter production	1365	1510	1674
	Consumption	1327	1185	1560
	U.S. Special Account purchases	7	192	155
Aluminum	Smelter production	1117	1127	1285
	Consumption	1111	1024	1312
	U.S. Special Account purchases	....	11	20
Tin	Smelter production	160	171	175
	Consumption	136	117	149
	U.S. Special Account purchases	24	53	30†

† Estimated.

CURRENT SHORTAGES

Let us analyze the extent and causes of present shortages. The figures of production and consumption in the free world issued by the Economic Cooperation Administration in Washington are given in Table I for the years 1948, 1949, and 1950. The United States "Special Account purchases," which are generally taken to represent the purchases for stockpiling, are shown separately. Table II summarizes the position for the period 1948-50. During those three years, the United States Government stockpiled some 5% of the world's total production of copper and zinc, 8% of that of lead, and no less than 21% of the total production of tin, and that is the cause of our present shortage. The mine production for the same three years (1948-50) is summarized in Tables III and IV.

Since 1950 the position has changed a little, and now I think that it is our defense requirements which are throwing production and consumption out of balance. Stockpiling has been at a very much lower rate this year, and will probably be smaller still next year.

TABLE II.—*Summary of Production and Consumption for 3-Year Period 1948–50.*

(Thousands of metric tons)

	Total Production	Total Consumption	Excess or Deficit	Total U.S. Special Account purchases for 3 Years	Total Excess or Deficit
Copper	7065	6940	+ 125	384	— 259
Zinc	5063	4868	+ 195	273	— 78
Lead	4549	4072	+ 477	354	+ 123
Aluminum	3529	3447	+ 82	31	+ 51
Tin	507	402	+ 104	107	— 3

TABLE III.—*World Mine and Smelter Production of Copper, Zinc, and Lead 1948–50.*

(Thousands of metric tons)

		1948	1949	1950
Copper	Mine production	2120	2051	2280
	Metal content of scrap	155	199	239
	Combined total	2275	2250	2519
	Refinery production	2291	2237	2537
Zinc	Mine production	1542	1593	1764
	Metal content of scrap	64	83	130
	Combined total	1606	1676	1894
	Smelter production	1564	1680	1819
Lead	Mine production	1282	1347	1466
	Metal content of scrap	68	137	143
	Combined total	1350	1484	1609
	Smelter production	1365	1510	1674

TABLE IV.—*Summary of Mine and Smelter Production for 3-Year Period 1948–50.*

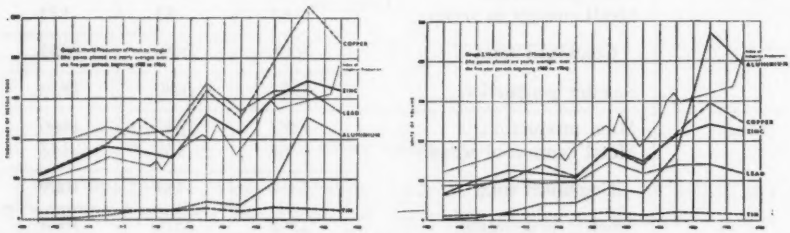
(Thousands of metric tons)

	Mine Production + Scrap for Smelting	Smelter Production	Excess or Deficit
Copper	7044	7065	— 21
Zinc	5176	5063	+ 113
Lead	4443	4549	— 106

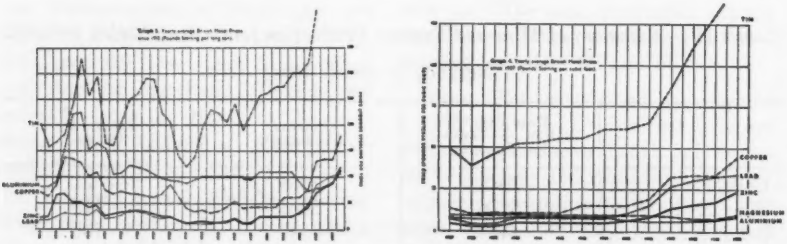
THE LONG-TERM DEMAND

In a general way it is easy to determine roughly the requirements for the next few years, but it is very much more difficult to determine the consumption trends farther ahead. Recently we have been going through a period of accelerated industrial activity, and over the last fifty years there has been a steady upward trend in production, despite fluctuations. The most spectacular rise has been that of aluminum, particularly in terms of volume (Figs. 1 and 2).

Price also has a very important influence on the consumption of metals, though it is overshadowed just now by shortages. Between the wars there does not seem to have been any significant relationship between price and output, the slow downward trend in prices corresponding with the slow increase in the value of money as measured by the wholesale price indices (Fig. 3). Prices began to move upwards at the outbreak of war, and continued to do so until the middle of 1948, when there were some minor fluctuations. Prices have again started to mount, the falls being arrested by the new demands which occurred after the start of the Korean war. Between the wars the relationship between the prices of the different metals never changed significantly, but aluminum is now very much cheaper than the other non-ferrous metals by volume, and I think that this is of great importance, because the price gap between the old and new metals may become even wider in future (Fig. 4). The average costs of copper, zinc, and lead may be expected to rise when new production is brought in, since this will mean the use of lower-grade ores; but with aluminum and magnesium there are abundant supplies of ores, and new production will depend on increasing the supply of electric power. The prospects are good in many parts of the world, so that aluminum looks like competing favorably in the future on a cost basis.



FIGS. 1 and 2.—World Production of Metals (1) by Weight and (2) by Volume, 1900–50.



FIGS. 3 and 4.—Average Annual Price of Metals in Britain (3) by Weight (1913–50) and (4) by Volume (1937–50).

Magnesium is another metal which is likely to be very important in the future, on account both of its properties and of its comparatively low price. At present its price per pound in the United Kingdom is about twice that of aluminum, but its specific gravity is only 1.7, compared with 2.7, so that the price per cubic foot is not much greater. The price of magnesium is now much higher here than it was a year ago, probably because of the sudden increase in the demand as a result of rearmament. In the U.S.A., however, the price is still only 35% above that of aluminum. At the end of the war huge stocks of magnesium were left over, so that production virtually ceased, and it has only just started again.

The low prices of aluminum and magnesium when compared with the older metals on a volume basis mean that we are now faced with an entirely different pattern of consumption from that which prevailed between the wars, and that more and more non-ferrous metals are becoming available for general use. The indications are that, as consumption grows, aluminum and magnesium will take an increasing share of it, and thus the rise in the consumption of copper, zinc, lead, and tin is likely to be less steep than the rise in industrial production throughout the world. This has already occurred in the United Kingdom, where industrial production from 1946 to 1950 rose some 40%, though the consumption of various metals rose by very different percentages, e.g., aluminum 56, zinc 13, copper 6, and lead 3; while tin consumption actually fell. Hitherto, a certain conservatism has caused the older metals to be chosen for many purposes because they have always been so used. Now, however, aluminum is establishing a tradition of its own which will tend to increase its use at the expense of the older metals, and the same applies in a lesser degree to magnesium.

Titanium is another metal for which a great future is predicted, though it seems likely to compete more with steel than with the non-ferrous metals. Plastics may make big inroads into the non-ferrous metals field in the future.

CIRCULATION OF SCRAP

In any survey of the pattern of future consumption, allowance must be made for the important role played by scrap, the amount of which will continue to rise in increasing proportion with the rise in consumption of virgin metal. Only when consumption rises quickly, as is now the case, does the available scrap tend to lag behind and to aggravate present shortages.

H. J. Miller estimates the total production of lead from 1847 to 1947 at 85 million tons, of which 65% may be ultimately recovered as scrap. In the same period 80 million tons of copper were produced, 60% of which may ultimately be recovered. This recoverable scrap constitutes a vast pool of metal which will continually be reused and recirculated, virgin metal being constantly added to it as is necessary to meet demands.

Lead is the classic example of the importance of scrap, which nowadays amounts to some 40% of the metal consumed. The greater part of this is recovered by salvage, the remainder being process scrap. The lead-scrap pool dates back a very long time, and its growing size may in fact account for the slight decline in the consumption of virgin metal. Until recently the main dissipating use of lead was in pigments, but now, of course, we have the very important use in the U.S.A. for high-

octane petrol, and that may change the situation in a few years.

Copper is another almost indestructible metal, but its cycle of return to the pool is much longer. At present about 35% of the copper used comes from scrap, of which between one-half and two-thirds is the result of salvage, the remainder being process scrap. Copper has been used on a large scale only for a generation or two, and in twenty or thirty years from now the pool may have grown to be just as important as that of lead, or perhaps even more important. The only dissipating use is for copper sulphate.

With zinc, the scrap now represents only some 25% of the metal consumed, but the prospects of the pool growing are not so good, since some of the main uses of zinc require the complete loss of the metal, as in protective coatings and in pigments.

Tin is used mainly in an indestructible metallic form. Its chief use is in very thin coatings on steel, and most of this metal is not recovered, although, because of the high price, 20-30% of the tin used in this country and in America is secondary metal from various sources.

I feel that the best form of conservation lies in reclaiming metals rather than in prohibiting their use.

THE WORLD RESOURCES

Before considering the resources of ores which are available to meet future requirements, some general observations on world resources may be worth making. First, up to the present certainly not more than two-thirds of the land surface of the earth can be said to have been explored for minerals. While it is probable that the remaining third will be found to contain less mineral wealth in proportion, there must nevertheless be huge unknown resources still awaiting location. Most of the great discoveries in the past twenty years have been made in the so-called explored regions, and these will no doubt continue. It must not be forgotten also that the period between the two world wars was one of over-production, when there was no urge to seek new ores.

Another factor which has an important bearing on the estimation of world resources is that in the last twenty years important new methods of locating ore bodies have been introduced, although science has not yet succeeded in evolving any method of locating really deep deposits.

The present high prices have led to much more active prospecting, the results of which can be seen in the large number of new mines and workings now being opened up; and here it is to be noted that these ventures have been based on work begun when prices were much lower than they now are. Another result of the price stimulus will be the exploitation of poorer ores than those previously worked, and, as extraction techniques improve, the amount of such ores increases. The mining of ores at lower level will also prove economic. Many mining companies know quite well what additional reserves can be reckoned on as prices advance.

I now propose to deal with each metal separately and to examine the estimates of resources made by different experts.

Aluminum. — Aluminum constitutes 8% of the earth's crust, though only bauxite is being mined on a large scale. Bauxite is, however, found in large quantities in many parts of the world, and there is no immediate prospect of other sources having to be used. The only factor likely to limit aluminum production is the availability of electrical power, the cost of which constitutes about 60% of the present cost of the metal. The future of aluminum

is very closely linked with the development of hydro-electric power or other large-scale plants for producing electricity cheaply. It is estimated that the total world output in 1951 will be 15% higher than in 1950, and by the end of 1953 as much as 50% higher than it is today. A dozen new smelters are in course of erection in different parts of the world, the largest being in North America.

Magnesium. — Magnesium is in a similar position to aluminum, in that it is very plentiful and is believed to constitute 2% of the earth's crust. It is obtained from deposits of magnesite and dolomite and from brines and seawater, and so is virtually unlimited. Its production generally requires electric power, though thermal processes are also used. The U.S.A. consumed about 20,000 tons of magnesium in 1950, and expect to use some six times this amount annually by 1960. Production is being increased accordingly.

Copper. — Authoritative figures for the reserves of copper are difficult to obtain. The total "officially reported" in the Yearbook of the American Bureau of Metal Statistics for 1951 is approximately 60 million metric tons, but this does not include a number of the largest mines both in America and elsewhere. From recent company reports, it is evident that approximately 7.9 million tons should be added to the above figure, but even this fails to include many important mines for which no reserves have been published, though they may be estimated at about 16 million tons. It is therefore safe to assume that there is a reserve of at least 100 million tons of copper at present, or sufficient for at least 44 years at the current rate of consumption.

Prospecting for fresh deposits is continually going on, and valuable "finds" are not infrequently made; it should be remembered, for instance, that the enormous ore-bodies of the Northern Rhodesian copper belt were unknown until about a quarter of a century ago, and other deposits of comparable magnitude may well be discovered in years to come. It is apparent, too, that as methods of extraction improve, grades of ore previously regarded as uneconomical will become workable; and the development and continual improvement of the froth-flotation method of concentration is a dominating factor in this direction.

For these and other reasons there seem to be no grounds for supposing that supplies of copper will be insufficient to meet the essential requirements of an expanding economy for many years to come.

Zinc.—With zinc, we have more estimates of the resources than with most of the other metals. The latest and most authoritative survey was given in 1948 by K. C. Dunham, who observes that a high proportion of the estimated reserves mentioned falls within the possible and speculative (inferred) categories; nevertheless, the estimates are made by experienced mining engineers and are not flights of fancy. Other reliable estimates have been made by W. R. Ingalls, in 1931, and by W. P. Shea, in 1940 and 1947. The figures, given in Table V, are very interesting, because these reserves appear to grow with each new estimate.

TABLE V.—*Zinc Consumption and Reserves.*

(In millions of metric tons)

Year	Annual Rate of Consumption	Estimated Reserves
1931	1.1	24.5
1940	1.8	39
1947	1.6	57
1948	1.8	65

Discoveries of new zinc deposits are being made in many parts of the world,

and are far too numerous for detailed mention. The most important are perhaps those in Canada and French North Africa. In Canada the new Barvue mine alone expects to produce 4000 tons of ore per day in 1950, and surface drilling has already outlined 17 million tons of ore.

The exploitation of poorer ores, as well as of the vast heaps of slag from lead blast furnaces which lie all over the world, will be a further source of metal, assuming that present prices continue. Thus at Bergamo, in Italy, a new smelter is being built especially to deal with the abundant local supplies of poor-grade ore.

Lead.—In the case of lead there has so far not been any overall world shortage, though there have been local shortages in some countries which in future may become more serious, particularly if the shortages of zinc and copper continue. Since zinc and lead are generally found together, the new mines referred to under zinc will provide an important addition to the reserves of lead. Shea and Dunham have both made estimates of the world reserves of lead, shown in Table VI.

Tin.—Since the end of the war the production of tin has been in excess of consumption, the shortages experienced during and immediately after the war having allowed substitutes to become well established. It has been said that the resources in Malaya, from which about 35% of the world's tin is obtained, are rapidly being depleted, but the real trouble is that prospecting has been prevented by local disturbances. Good reserves are known to exist in Indonesia, the Belgian Congo, and Bolivia.

TABLE VI.—*Lead Consumption and Reserves.*

(In millions of metric tons)

Year	Annual Rate of Consumption	Estimated Reserves
1947	1.8	32.5
1948	1.6	31

In general, the reserves of the principal non-ferrous metals seem to vary according to likely future demands with aluminum at the top of the list and lead at the bottom. It is fashionable nowadays to quote the known reserves of metals in terms of their life at the present rate of production. I have therefore reproduced in Table VII figures prepared in 1949 by Elmer W. Pehrson, of the U.S. Bureau of Mines. Since those estimates were made, there have been some substantial new discoveries, so that I do not think that they represent by any means the last word.

TABLE VII.—*Estimated World Reserves of Non-Ferrous Metals (1949).*

Metal	World Reserves	
	Thousands of Metric Tons	Years' Supply at Current Rate of Production
Bauxite (crude ore)	1,400,000	200
Copper (recoverable content)	100,000	45
Zinc (gross content)	70,000	39
Tin (recoverable content)	6,000	38
Lead (gross content)	40,000	33

TABLE VIII.—*Consumption of Copper and Zinc (1938, 1949, 1950, and 1951).*

	Copper	U.K.	U.S.A.	Belgium	France	Australia	Italy	Canada
1938	Quarterly average	66,400	96,112	7,500	28,025	4,350	23,000	9,247
1949	Quarterly average	80,975	234,750	11,750	30,050	8,325	15,800	23,000
1950	Quarterly average	84,775	326,250	14,250	29,250	8,900	22,525	24,275
1951	First quarter	83,100	313,000	17,800	37,200	8,505	29,000	29,200
	Second Quarter	87,700	316,000	19,200	31,300	8,900	29,000	....
	Fourth Quarter allocation	87,450	317,460	16,480	25,030	8,500	23,080	27,580
	Zinc							
1938	Quarterly average	54,850	102,822	25,875	22,250	8,060	8,775	9,017
1949	Quarterly average	50,475	171,500	15,000	26,750	11,250	7,025	10,350
1950	Quarterly average	60,150	249,200	16,250	25,250	13,000	8,750	12,750
1951	First quarter	46,400	195,200	19,000	27,100	12,100	11,000	14,100
	Second Quarter	46,600	....	29,000	27,900	13,100	11,000	15,400
	Fourth Quarter allocation	58,450	221,461	22,160	26,910	13,010	9,390	12,780

OVERCOMING THE PRESENT SHORTAGES

Having shown that the long-term supplies should cause little anxiety, I must now turn to the problems of the present shortages, where the position is much less clear. I think it is evident that they were brought on by stockpiling and are now being aggravated by the demands for defense. Furthermore, as always, every shortage seems to create an extra demand. The present situation appears likely to continue for some time, and to be followed by a fairly heavy demand for civilian consumption for an indefinite period. All this uncertainty affects the flow of investment towards the development of mining and smelting, and the time-lag between the decision to open a new mine or build a new smelter and actual production must always be allowed for. Moreover, it must be realized that this is almost the first time, apart from war conditions, when metal consumption has exceeded production, and producers naturally fear a sudden return to the former state of affairs. Nevertheless, many new mines are being opened up, and the *Engineering and Mining Journal* mentions no less than fifty new copper, zinc, or lead mines as having been opened during the first six months of this year. I believe that the real shortage is only a matter of a few percent, and is likely to be over fairly soon; but we are always faced with the difficulty that we cannot determine the extent of the demand so long as consumption is limited by the shortage of metal.

Before considering our own prospects, it is interesting to see what has been happening to consumption in the leading countries since the shortage began. The figures in Table VIII show that consumption has risen in almost every country, with the exception of the United Kingdom and the U.S.A. In other words, the countries with the biggest purchasing power have felt the shortage more acutely than the others.

The causes of this situation seem to be fairly clear. First, there is the rapid growth of the fabricating industries in exporting countries such as Canada and Australia. In Australia the home consumption of zinc has been encouraged

by the fixing of an exceptionally low internal price. More recently, the Canadian fabricators have been able to buy metals more cheaply than the users of Canadian metals in this country, and the same price differences can be seen in other exporting countries. This, of course, is not a new trend, but it is being given further encouragement now that the exporting countries find that money is losing its value and often does not command the equipment and machinery which they need.

Secondly, planning and control have become features of economic policy both here and in the U.S.A. In both countries efforts have been directed towards keeping the price of metals down, and recently even the U.S.A., with its colossal dollar purchasing power, has found itself outbid for foreign ores simply because it could not turn the ores into metal which it could sell at the home price.

The wholehearted determination of America and ourselves to solve our difficulties and those of the free world generally by international planning and control is shown by the setting up of the International Materials Conference, which has the object of ensuring the fair distribution of the raw-material resources of the world. Here it may be remembered that previous schemes for the international distribution of metal have seldom proved successful, and it remains to be seen whether the threat of aggression may make the chances of success better now. If the International Materials Conference allocation scheme should fail, the U.S.A. may well resort to buying for its armament needs at higher prices in the open market. This in turn may lead to a general resumption of free trading in metals, and possibly to the weakening of the present arrangements whereby we and the U.S.A. are able to get good supplies of metal more cheaply than most other countries.

The loss of the free market means that the planners have now to decide for what purposes metals or their substitutes are to be used. In any case, the pattern of control and planning seems likely to last for some time, and the prospects of an early return to free markets are rather remote. In this connection it is interesting to examine Fig. 5 which shows the changes in production

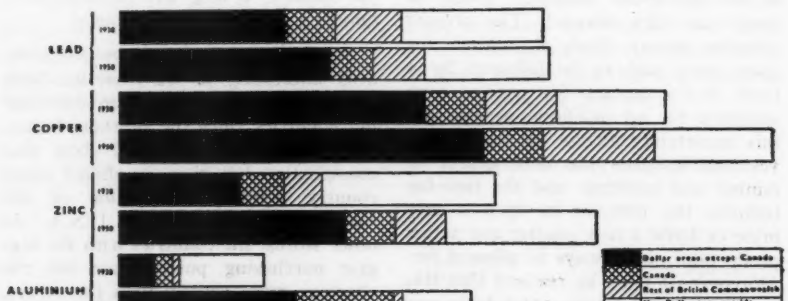


Fig. 5.—World Distribution of Metal Production Before and After the War.

that took place between 1938 and 1950. It will be seen that during that period nearly all the new production was in the dollar area. It seems to me that there are three ways in which we might consider improving our present position: (i) by placing long-term contracts, (ii) by encouraging production in non-dollar areas where we may expect to enjoy a first call on new output, and (iii) by maintaining and fostering ventures with headquarters in London.

We and the U.S.A. have already placed long-term contracts, often accompanied by loans, a condition of the loan being the repayment of the money in metal arising from the new production. An outstanding example is our arrangement with the Canadian aluminum producers. The U.S.A. has made rather similar arrangements with the use of E.C.A. funds, the loans being made to mines and smelters in Europe. Incentives to increase production and to bring new mines into operation have been adopted in other countries and, since the development of mining in the Commonwealth is still largely based on London, we might also take steps to ensure that incentives at least as effective are available to firms with mines in Britain itself and in the Commonwealth.

In the U.S.A. approved new mining and smelting projects can secure accelerated tax amortization. Eighteen of the new projects so favored are expected to yield by 1955 96,000 metric tons of copper, 106,000 metric tons of lead, and 230,000 metric tons of zinc. Aluminum production is being increased by the same means, and a total of 1,175,000 tons is expected to be produced by 1955, and 178,000 tons of magnesium. The United States authorities have also undertaken, in the event of a fall in prices, to purchase metal or concentrates at an agreed floor price in the case of other new ventures for a period sufficient to ensure the return of capital. In addition they have made advances for approved prospecting ventures repayable in terms of metal or ores. In Canada a new mine is allowed exemption from tax for three years, and the high rate of mining development there is good evidence of the effectiveness of that method of encouragement.

Before applying such incentives here, however, our taxation laws would appear to need overhauling, since at present they represent a serious drawback to London-based mining companies, which have tended to remove their headquarters elsewhere in recent years. We cannot overlook the fact that these London-based companies have been our best and most certain sources of supply in the past, and may be even more important to us in the future. It seems unfair that these companies, the operations of which are carried on overseas, should be liable to United Kingdom tax on all their profits, whether or not they are remitted to this country. Moreover, British-controlled mining companies do not enjoy depletion allowances comparable with those in other countries, and particularly in North America, where large depletion funds can be built up out of tax-exempt current revenue, these funds being available for further exploitation when existing ore-bodies are worked out.

These are but a few of the changes which our taxation laws would seem to need, if British companies are to continue to play a part in opening up world resources. However equitable our mining taxation may be compared to that imposed on other United Kingdom industries, it falls far short of the practice in other countries, and that is the real criterion. Not a single mining company of any size has been floated in the United Kingdom since the war, and it seems certain that none will be under present conditions.

Metals as Natural Resources

BY PROFESSOR S. ZUCKERMAN,* C.B., F.R.S.

The shortages with which we are concerned signify far more than transitory dislocations of the market. They mean that all over the world manufacturing industries are turning over much faster than production industries. The increase in population, the facts that standards of living are rising everywhere, that the backward races are becoming industrialized and that their consumption is going up, that rearmament is taking place, and that stockpiling is occurring all add pressure to the demand on resources. But not one of these factors taken separately is new. There are two things, however, that do seem to me to be new. The first is the fact that the rate of demand appears to have gone up enormously in the last ten years. The second is that, much to the surprise of a number of prophets, there has been no slump.

The central problem to which we have to direct ourselves is the disparity between demand and supply. This disparity was the theme of a series of articles which recently appeared in the *Economist* entitled "Agenda for the Age of Inflation." These expressed the view that as far as one can see ahead there is going to be too much money chasing too few goods. That is another way of saying that the rate of demand is going to rise at a greater rate than the rate of supply, and that the value of money will decrease.

In a recent paper, Professor Lewis, the head of the Department of Economics at Manchester University, has assembled figures for countries on this side of the Iron Curtain to show that the fundamental reason for the overall problem which faces us today is not excessive demand but shortage of supply. He does not accept the conclusion that in the commodities field there will be a balance if one or two extraneous factors are removed.

He points out that if the rate of growth of world industry over the past 70 years is plotted, it is found—surprisingly—that the rate of increase of growth of manufacturing industry has been falling off recently in the world and not rising. The rate of increase for the 40 years before 1914 was 3.7% per annum, and since then the rate of increase has fallen to 2.5%. The same trend is demonstrated in the figures for the U.S.A., where between 1873 and 1913 manufacturing industry increased at the rate of 4.8% per annum, whereas from 1913 to 1929 the rate of increase was 3.8%, and from 1929 to 1950 it was 3.1%. In other words, and relatively speaking, the rate of growth of demand has been declining.

Professor Lewis also provides figures which show that whereas before 1913 the raw-materials industries of the world were growing roughly at the same rate as manufacturing industry, since then there has been an increasing disparity (Table IX).

The growth of manufacturing industry is paralleled by the growth of the metals and fuel industries, and there is very little disparity there. The main disparities are in food production, population increase, and agricultural raw materials, which include, of course, all fiber production. Within each of these

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TABLE IX.—*Increase in Productivity 1913–50.*

	1913	1929	1937	1950
Manufacturing production	100	152	172	247
Food	100	116	125	131
Agricultural raw materials	100	149	194	178
Metals and fuel	100	150	170	239
All primary production	100	127	140	155
World population	100	113	124	138

classes there are enormous differences between various commodities, and the separation of these classes is naturally very broad, but in general let us agree with Professor Lewis that there has been this divergence and let us also accept the very important fact which emerges, namely that in the world today the primary reason for the disparity between supply and demand is shortage of production of primary materials and *not* excessive demand.

Turning to changes in the pattern of consumption—a factor which Mr. Stubbs has illuminated extremely well —we see these changes occurring partly because of the development of relative scarcities in the amounts of lead, tin, zinc, and so on, which are available, and also because of the intervention of new materials. As Mr. Stubbs has shown, these changes in availability have to be looked at not only in terms of volume, but also in terms of price. It is important to note here that, while the increase in scientific knowledge and in improved methods of dealing with minerals and metals has apparently reduced the cost of handling these commodities, nevertheless these economic benefits have become swamped, as far as the old, conventional minerals are concerned, by increasing labor costs, transport costs, and so on.

This does not necessarily apply, as Mr. Stubbs has also shown, to some of the newer metals, as aluminum, for example, the price of which is fairly constant. You therefore have a change in the pattern of relative values and a change in the pattern of relative availability, and these two things determine the changes in the pattern of consumption and also what we call "substitution," which will occur and which has always occurred whenever there has been an economic advantage to be gained by it.

On the other hand, as far as I can make out, substitution does not mean, or has never yet meant, any reduction in the use of a material for which a substitute is being found. Even though the production of lead has been falling over the years, nobody has suggested that the amount of lead which is available is not being used.

So far as the world as a whole is concerned, obviously the only way to overcome these difficulties in the long term is to see that capital is attracted to the raw-materials industries. The position is difficult for private investment. Private investors rarely go into food production abroad in a big way, and today it is plain that many people are nervous about investment abroad, not only because of political uncertainties but also because at present the private investor has to reconcile the advice of pessimists talking about long-term shortages and difficulties with the fact that at any given moment there may be a glut of some particular commodity.

If the world problem of stimulating the primary-materials industry is not solved by private industry, clearly Government investment has to come in, but I do not want to go into that aspect of the problem.

Having talked so far about the world problem, I should like in conclusion to refer to our own particular problem. In this country we are importers: we live by the added value that we give to raw materials which we get from abroad and which we then export. We get 50% or more of our food and 80% of our raw materials of industry from abroad. Our capacity to secure these depends on our competitive position in the world markets. Our competitive position is not as strong as one would like. In fact, if there is one point on which I disagree with the analysis of Mr. Stubbs, it is his suggestion that this country and the U.S.A. have been the two most powerful countries since the end of the war as far as world trade is concerned. I would say that we have been extremely limited in our competitive power in obtaining materials at various times. Because we are in a weak position, we must remember not only that the International Materials Conference is very important, but also that development plans in other countries can affect us enormously.

I think, as Mr. Stubbs does, that every encouragement should be given to the mining industries. I also feel that, in addition to overseas investment, we should not forget to survey our own country. It is unfortunate that the Mineral Development Commission was not set up. Circumstances prevented it, but it would have done a great deal towards a rational survey of the resources of this country. Furthermore, it might have done much to stimulate deep exploration, and at the same time it might have helped to bridge the gap between the gaining of new knowledge about our resources and the exploitation of those resources.

We have to take a rational view of the future. I myself am not convinced that the price mechanism alone is a sufficient guarantee that materials will be there when they are required. We have to reconcile private and public interests in some way and find a means whereby private initiative and skill and enterprise can be so unleashed that it will be to the public good, not only in this country but over the whole world.

World Demand and Resources of Iron Ore

BY T. P. COLCLOUGH,* C.B.E., D.SC.

The steel industry has been well described as one of the basic industries of the modern world, and the production of crude steel in the world has risen from about half a million tons in 1870 to over 160 million tons in 1950. The fundamental raw materials of steel are iron ore and scrap to furnish the metallic iron, and coal to supply the necessary heat required in the operations.

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SCRAP SUPPLIES

While the proportion of scrap used in steel-making may vary from country to country according to the process employed, the percentage of scrap arising over the world as a whole bears a fairly constant relationship to the gross tonnage of steel made. Taking a broad view, the rolling of steel, its processing into finished form, and the return of obsolete or used plant give in total a volume of scrap equal to roughly 50% of the ingot weight made.

PIG-IRON REQUIREMENTS

Again taking a broad view and averaging the yields for the various steel-making processes, the weight of metallics—scrap and pig iron—required for steel-making is approximately 110% of the ingot weight. It therefore follows that the pig iron required for steel-making is approximately 60% of the crude steel produced. To this must be added about 4% for the ferro-alloys consumed and pig iron used for the making of ingot moulds, giving a total blast-furnace product requirement of about 64% of the ingot weight made. The world production of 160 million ingot tons in 1950 required approximately 100 million tons of pig iron and ferro-alloys, as compared with a total pig-iron production of 113 million tons, the remaining tonnage being required for foundry and other types of pig iron.

IRON ORE

The total world production of iron ore in 1949 is estimated at practically 220 million tons. Distribution of the production of iron ore, pig iron, and steel among the principal countries is given in Table X, For convenience, the steel-producing countries of the world may be divided into four groups: (*a*) the United States and Canada, (*b*) Western Europe and the United Kingdom, (*c*) the U.S.S.R. and its associated countries, and (*d*) the rest of the world—South America, South Africa, India, and Australia. The production figures for these four groups are given in Table XI. The data for the U.S.S.R. are all estimated, and no useful purpose would be served by a detailed examination. It may be assumed that the ore and coal requirements for this group will prove adequate.

So far as group (*d*) is concerned, these industries exist principally to meet local demands and have adequate indigenous resources. It is not anticipated that, except in the case of South America, these resources can make a positive contribution to the requirements of the large consuming groups (*a*) and (*b*).

(*a*) *U.S.A. and Canada.*—The U.S.A. and Canada have a combined capacity for over 100 million tons of steel per year and require approximately 100 million tons of ore. The ore reserves are extremely large and, while enormous tonnages have already been extracted, further resources are being revealed. Experimental work on the beneficiation of the low-grade taconites, which are estimated at over 1 billion tons, has reached the stage of pilot-plant development, and large-scale production is ex-

TABLE X.—*World Production of Iron Ore, Pig Iron, and Steel (1949).*

(Million tons)

	Iron Ore	Pig Iron	Crude Steel
	%	%	%
U.S.A.	85.0—38.7	49.0—43.2	69.6—44.1
U.S.S.R.	35.0—16.0	16.4—14.5	23.2—14.7
France and Saar	31.4—14.3	9.9— 8.7	10.9— 6.9
Scandinavia	14.1— 6.4	0.9— 0.8	1.4— 0.9
U.K.	12.5— 5.7	9.5— 8.4	15.6—10.0
W. Germany	9.4— 4.3	7.1— 6.3	9.2— 5.8
North and West Africa	5.4— 2.5	....	....
S. America	4.6— 2.1	....	....
Belgium and Luxembourg	4.1— 1.9	6.1— 5.4	6.1— 3.9
Canada	3.3— 1.5	2.1— 1.8	2.8— 1.8
India	2.8— 1.3	1.6— 1.4	1.3— 0.8
Australia	1.5— 0.7	1.0— 0.9	1.2— 0.7
Others	10.3— 4.7	9.8— 8.6	16.4—10.4
Total production	219.4 million tons	113.4 million tons	157.7 million tons

pected within a very few years. Meanwhile, developments on a large scale are in hand for the exploitation of the vast reserves of high-grade ore in Venezuela and on the Quebec-Labrador border. Each will provide 10 million tons of ore per year. New developments are taking place in the American interests in West Africa, and there is a tendency to increase the import of ore from Sweden. These increased imports of ore must be used mainly at seaboard locations, and a second large steel-producing plant with a capacity of 2

TABLE XI.—*1949 Production of Iron Ore, Pig Iron, and Steel.*

(Million tons)

Group	Iron Ore	Pig Iron	Crude Steel
	%	%	%
(*a*) U.S.A. and Canada	88.3—40.2	51.1—45.1	72.5—46.0
(*b*) Western Europe and U.K. (inc. N. and N.W. Africa)	80.9—36.9	35.8—31.6	47.2—29.9
(*c*) U.S.S.R. and associated countries.	38.0—17.3	20.2—17.8	29.6—18.8
(*d*) Others	12.2— 5.6	6.3— 5.5	8.4— 5.3
Total production	219.4 million tons	113.4 million tons	157.7 million tons

TABLE XII.—*Iron Ore Available to Western Europe in 1949.*

(Thousands of tons)

Country	Production *	Imports				
		Other W. European Countries	N. Africa and Sierra Leone	America	Others	Total
Sweden	13,729	....	....	...	...	Nil
France/Saar	31,410	148	222	...	26	396
U.K.	12,457	4,391	3,569	713	22	8,695
W. Germany	9,362	4,100	289	67 †	62	4,518
Belgium/Luxembourg	4,137	8,920	110	38 †	23	9,091
Spain	1,852	....	....	...	...	Nil
Austria	1,488	415	81	...	87	583
Italy	521	....	99	...	66	165
Norway	413	39	....	...	...	39
Switzerland	120	38	....	...	...	38
Netherlands	Nil	412	262	43 †	...	717
Totals	75,489	18,463	4,632	861	286	24,242
Algeria	2,500					
Morocco	1,250					
Tunis	670					
Sierra Leone	970					
	5,390					

Summary of Western European Area

Total ore production	80,879	
Imports from America	861	
Imports from others	286	
		82,026
Less:		
Exports to America	2,191	
Exports to others	1,643	
		3,834
Net ore available		78,192

* Includes some pyrites and manganese ores.

† Brazil.

million tons per year is planned for the Atlantic coast. The known resources of iron ore are estimated as adequate to assure the life of the industry in the U.S.A. for over 100 years.

Canada, with its limited steel production of about 3 million tons per year, has ample reserves of iron ore, and will undoubtedly act as an exporter of ore to both U.S.A. and Europe, the chief limiting factor being the severe winter conditions which restrict exports to about six months of the year.

(*b*) *Western Europe.*—For reasons of geographical proximity, it is convenient to regard the ore-producing countries of North Africa and Sierra Leone as an integral part of this group. In 1949 this area produced roughly 47 million tons of steel, 36 million tons of pig iron, and 81 million tons of ore. It is well known that the native ore resources of France, Germany, and Britain are of comparatively low grade as compared with the ores available in America and Sweden. As a result, the weight of material to be mined, carried, and processed per ton of product is higher in this group than in any other producing area in the world. The details of ore production, by country, are given in Table XII.

This table shows that approximately 95% of the ore produced in the area was consumed within its borders. Three countries show apparent deficiencies: the deficit of the largest importer, Belgium, Luxembourg, importing 9 million tons, is only apparent, since practically the whole of this ore is imported across the border from France. The two real importing countries are the United Kingdom and Western Germany, and to these countries supplies of ore from external sources are vital.

FUTURE REQUIREMENTS

Each of the Western European countries is engaged upon the task of modernizing and expanding its steel production. The provision of the estimated increase in demand of raw materials presents one of the outstanding problems. The production of iron and crude steel of the different countries for the year 1949 and the target estimates for the middle 1950s are given in Table XIII. It will be noted that, while both pig-iron and steel targets show substantial increases, the proportion of pig iron to steel rises from 75% in 1949 to 82.5% in 1955. It is self-evident that the manufacture of over 50 million tons of pig iron per year will result in a substantial increase in the demand for iron ore. The first step to meet this, already in hand, is to increase production at the existing sources of supply, or to utilize more fully the present tonnage of materials mined.

In pre-war days considerable difficulty was experienced in disposing of fine ores which were inevitably produced in the mining operations. Mechanized and larger-scale operations will increase the proportion of these fine ores. This fine material must be utilized, and for this purpose all ore users have been urged to install further sintering capacity in order to deal with iron-ore fines, pyritic residues, flue dust, and other iron-bearing materials. Considerable progress has been made in this direction in the United Kingdom, and it is anticipated that by 1953 the production of sinter in this country will be of the order of 5.25 million tons, as compared with slightly over 3 million tons in 1949.

Each of the ore-producing countries in this group has submitted plans for the further development of its resources, and Table XIV gives an indication of

TABLE XIII.—*Western European Production and Targets of Iron and Steel.*
(Thousands of metric tons)

Country	Pig Iron			Steel		
	1949	1955	Increase, %	1949	1955	Increase, %
Austria	838	1,200	42	835	1,300	55
Belgium	3,749	4,870	30	3,849	4,850	26
France and Saar	9,927	14,000	41	10,909	14,800	35
W. Germany	7,140	11,500	61	9,156	13,500	47
Italy	393	1,450	269	2,055	3,100	51
Luxembourg	2,372	3,300	39	2,272	3,100	36
Netherlands	434	540	24	437	770	76
Norway	61	75	22	61	150	149
Spain	615	800	30	710	1,000	41
Sweden	811	1,250	54	1,370	2,050	50
United Kingdom	9,499	12,185	28	15,553	17,500	12
Totals	35,839	51,170	42	47,207	62,120	31

the quantities of ore and their iron content which it is estimated will be available for the years 1953 and 1960 from these sources. It will be seen that the anticipated production of 48 million tons of iron would be approximately equal to the amount needed for the manufacture of 51 million tons of pig iron. It is, however, undesirable, if not impracticable, to continue imports and discontinue the export of ore to other groups. If the export of ore is to increase proportionally, say from 4 to 6 million tons per annum, then new additional sources of ore supply must be established.

It is well known that large reserves of iron ore in Northwest Africa which are as yet unsurveyed or undeveloped can, under certain conditions, be made available. The Sierra Leone deposits can be mined on a larger scale and exported through the present port of Pepel. Work is already in progress to develop mining operations and a port at Conakry in French Guinea, and survey work is proceeding on known deposits in Mauretania. These, if developed, should be capable of producing together a total of 8-10 million tons of ore.

ECONOMIC CONSIDERATIONS

Britain, in particular, and Western Germany depend to a very marked extent on the import of ore. The new sources of supply in general present increasing costs of equipment and greater distances of transport. It is essential that these new enterprises should be based on a scale of production sufficiently large to carry the capital charges involved and at the same time reduce freight charges by the handling of the material in larger units of volume. This raises a further outstanding problem, namely the provision of new shipping to carry the increased tonnage and the building of ships of such a size and design as to give the maximum efficiency and economy in transport.

TABLE XIV.—*Estimates of Iron Ore Production in Western European Area.*

(Millions of tons)

Country	Iron Content, %	1949		1953		1960	
		Ore	Iron	Ore	Iron	Ore	Iron
Sweden	63	13.73	8.65	16.7	10.52	19.5	12.28
Norway	66	0.41	0.27	1.33	0.88	2.5	1.65
France	32.5	31.41	10.21	39.0	12.67	40.0	13.00
Luxembourg	30	4.14	1.24	7.0	2.10	7.0	2.10
W. Germany	30	9.36	2.81	9.65	2.89	16.5	4.95
United Kingdom	30	12.46	3.74	15.5	4.65	18.3	5.49
Austria	36	1.49	0.54	2.55	0.92	3.0	1.08
Italy	45	0.52	0.23	1.03	0.46	1.10	0.49
Spain	48	1.85	0.89	2.3	1.10	2.35	1.12
Others		0.12	0.03	2.0	0.94	2.75	1.36
		75.49	28.61	97.06	37.13	113.00	43.52
Algeria	52	2.50	1.30	...	...	3.25	1.69
Morocco:							
French	45	0.37.	0.17	...	...	0.75	0.34
Spanish	58	0.88	0.51	...	...	1.20	0.70
Tunisia	52	0.67	0.35	...	...	1.00	0.52
Wabana	52	0.71	0.37	...	...	1.75	0.91
Brazil	60	0.15	0.09	...	...	0.30	0.18
	...	5.28	2.79	...	...	8.25	4.34
Totals	...	80.77	31.40	...	...	121.25	47.86
Less exports	...	3.83	2.37	...	...	6.00	3.70
Net available	...	76.94	29.03	...	...	115.25	44.16

It further demands the installation of modern equipment and port facilities for the rapid unloading of the ore ships and avoidance of delays in port in order to secure the maximum economic use of the ships available. It is hoped by these means to offset in a large measure the increase in costs arising from present conditions. Steps to meet these demands are already in hand in this country.

Despite the magnitude of the problem, the difficulty arising from increased capital costs, and the necessity for more adequate shipping and unloading facilities, there would appear to be no doubt that the proposed iron and steel programs can be met, provided that the plans already formulated are attacked with vigor and fully implemented.

WARTIME LOGISTICS ABOARD SHIP

CAPTAIN CARL J. LAMB, USNR

THE AUTHOR

who spent three years at the Naval Academy and was commissioned in the Naval Reserve in June, 1917, has contributed six previous articles to the JOURNAL. In addition to a long period of time in the central station and marine departments of the Westinghouse Electric Corporation, he has spent many years at sea in the Navy and Merchant Marine, and holds unlimited Marine Chief Engineers License, steam and motor, in addition to professional Engineer licenses for the states of Connecticut and Indiana. At the present time Captain LAMB is again on active duty as Supervisory Inspector of Naval Material at Houston, Texas.

As the result of a year of partial mobilization, the fact is being brought home to responsible people in and out of the military services that many of the vital raw materials necessary to our military services are not available in the quantities essential to secure victory. One of the most vital of these raw materials is petroleum, without whose fuel and lubricating products no part of our military or industrial machine could function.

The brief and rather elementary account of the experiences of one Engineer Officer which follows is not intended to instruct the exceptionally able group of design and operating naval engineers responsible for fleet efficiency. The main intent is to cause thought, provoke discussion and to stress the importance of logistics and their partial application, aboard the individual ship. It is hoped that these experiences and observations will be useful to many of those reserve officers who will be operating naval engine rooms when the next all-out mobilization should occur.

Many of the peacetime economies and practices of the naval regular establishment are unknown to the average civilian, who is not usually aware of water, light, fuel or power shortages. Automatically, to most civilians, a faucet is turned and out comes water, a switch is operated and presto—there is light.

In training reserve components, during the relatively short time available, there is little or no time to cover the points discussed here. Because of the rapid expansion of the Navy during World War II, the high percentage of new people not aware of the logistic importance of conserving fresh water, as an example, the per capita consumption rose from around 20 gallons per man per day to well in excess of 30 gallons per man per day. This represented a 50% increase in the fuel required to evaporate that water!

During the emergency preceding World War II, while the writer was serving aboard the U.S.S. *Vincennes,* Rear Admiral (then Captain) Thorwald A. Solberg, who had developed

the Navy method of treating boiler water, suggested to the Engineer Officers of the Fleet the possibility of treatment of evaporator feed (sea) water with colloidal starch in accordance with a procedure he had worked out on a laboratory scale, with the hope of reducing or eliminating scale formation. Admiral Solberg's suggestion aroused considerable interest, and was tried out widely. Due to lack of appreciation of the exact proportioning involved, and the use of inadequate equipment, many ships soon abandoned the experimental work. The *Vincennes* persevered and developed, under Captain (then Commander) Noble W. Abrahams, the Engineer Officer, the practical and efficient use of colloidal corn starch to prevent the scaling of evaporator tubes.[1]

The starch treatment, by preventing scale formation, produced an appreciably greater quantity of water at a reduced fuel consumption. Following that development, all current uses of fresh water aboard the *Vincennes* were examined critically and eventually it was found possible to make appreciable reductions of water consumption as follows:

a. The use of sea water instead of fresh water in the vegetable preparation room (only when outside of the 50 fathom curve) saved 1400 gals. per day.

b. As the result of careful experimentation it was determined that cleaner, softer, whiter clothes could be produced by the laundry, if the first two rinses were made with sea water instead of fresh water. This saved 7000 gals. per day and in addition reduced the amount of bleaching compound required.

Because of experience with several oil companies between wars, it was appreciated when on duty in the Pacific after 7 December 1941, that supplies of fuel oil and petroleum products would be critical. Considerable thought was given, therefore, to the reduction of fuel oil consumption, while serving successively as Engineer Officer of the U.S.S. *Copahee, Indianapolis* and *Atlanta.* In addition to treating the evaporator feed water with starch, the use of sea water in vegetable preparation rooms, and the use of two salt water rinses in the laundries, the following additions and changes in existing operating procedure were established, for the reasons given:

a. Lubricating oils contain approximately 18,000 btu per pound, and vegetable oils approximately 14,000 btu per pound. Accordingly, all spent, dirty or contaminated lubricating oils from aircraft engine crank cases, main turbine systems, auxiliaries, motor boats, hydraulic systems, etc., which could not be reclaimed for re-use as lubricants by settling and centrifuging, and all rancid vegetable oils from the galley, were struck down into the bunkers. On the three vessels mentioned, this amounted to an average gain of 100,000 gals. per ship per year, or a total saving of 300,000 gals. of bunker oil on the three ships over a period of three years.

b. Burning of oil by heating only to those temperatures which would give 150/SFU viscosity at the sprayer plates, instead of the then existing practice of heating to 160°-180° F. It was found that all of the oil received aboard during the war in the Pacific from 1942 to 1945 required heating to only 110°-120° F. to obtain the ideal viscosity for proper combustion. As a result, the oil could be heated by auxiliary exhaust steam instead of by live steam, and consequently average fuel oil consumption was reduced by approximately 2%.[2]

c. By eliminating the "light brown haze" and using 25% excess air, in conjunction with burning oil at the correct temperatures, it was found that practically complete and perfect

combustion was obtained, to the extent that the boilers were always so clean and free of slag and soot on the fire sides, in the *Indianapolis* and *Atlanta,* that soot blowing was no longer necessary. When it is considered that tests on both ships showed an average fuel consumption of 700 gal. per night to blow tubes, this saving of 700 gal. per day was appreciable.[2]

d. During an extended period of time, some of the materials of construction of lamp bulbs were critically short, and there was a consequent real shortage of these bulbs. Tests on the *Copahee* and *Indianapolis* indicated higher compartment temperatures and shorter life of bulbs, when the observed wartime practice aboard many ships, of leaving all lamps on, all the time, day and night, was followed, than when all lamps in compartments, rooms, offices and spaces not occupied, were turned off. In addition, since fluorescent lights consume only approximately ⅓ the current required by Mazda lamps for the same light level, such lights were obtained and installed by ship's force in offices, rooms, barber shop, wardroom, etc. In order to assure that only those lights were burning which were needed, the assistant engineers and all Engineering Chief Petty Officers acted as permanent "light" police. Careful estimates showed an average saving of approximately 100 gal. of fuel oil per day, and a reduction of almost 40% in the replacement of light bulbs.

e. By constant adjustment of trim and mean draft on the three vessels mentioned, to maintain designed conditions as nearly as possible, appreciable savings in fuel consumption were made, in addition to important gains in stability.

f. During a large part of the war the Fleet and Task Force commanders required boiler power available for full power upon an hour's notice. Most ships, as a result, cruised at relatively low power with all boilers on the line. Operation at such low steam demand (percentage of rating) resulted in extremely low boiler efficiencies, and wasted excess auxiliary steam. On both the *Indianapolis* and *Atlanta,* we cruised on only half of our boilers, keeping pressure on the other half at all times, by lighting off and raising pressure every eight hours, under which condition we never entirely lost pressure, and thus did not lose the latent heat. Our tests showed comparative savings of around 1000 gal. of fuel oil per day by this procedure.

g. In addition to the efficiency to be gained by keeping the ship as near designed draft and trim, as possible, the writer has always had a firm conviction that the less the roll of the ship, the less fuel will be required to maintain desired speed. Accordingly, due to the adverse free-surface effect of wing bunkers when filled to only 95%, it was the invariable rule aboard *Indianapolis* and *Atlanta* to fuel at 100%, and to maintain all tanks containing fuel or water full at all times. While no accurate estimate of fuel savings could be arrived at, there was a very noticeable reduction of roll and consequent increase of stability. When the Third Fleet passed through the eye of a typhoon off Okinawa, *Atlanta* rolled 38°, while the cruisers immediately ahead and astern of *Atlanta* were rolling over 50°.[3]

h. The availability of high quality make-up feed water, in the quantities needed, is of vital importance to any steam-propelled vessel as is well known. Aboard both the *Vincennes* and *Indianapolis,* the average make-up feed consumption was 4000 gals. per day. When putting the *Atlanta* into commission we were warned that operating experience of the previous

18 cruisers of her class demonstrated make-up feed requirements of 10,000 to 12,000 gals. per day, and the "water hours" would be necessary. A careful examination of the plant design indicated no possible requirements for over 4000 gals. per day if properly operated but upon going into commission the actual make-up feed required at first was over 12,000 gals. per day. A thorough check indicated that the excess of over 8000 gals. per day wasted make-up feed water was in either the laundry or sculleries. Close observation of both operations disclosed the needless wastage of water to be in the sculleries. By making "A" Division Officer responsible for the operation of the sculleries, and requiring inspections of the sculleries three to six times per day, the *Atlanta* operated from then on with make-up feed requirements of only 3500-4000 gals. per day. It was never necessary to enforce water hours, nor to operate the evaporators more than 18 hours per day.

The above examples are of necessity confined to personal experience aboard individual vessels. The results obtained are, however, of appreciable value, if applied to an entire fleet. It was a matter of real pride to the subject ships that fuel savings were not only substantial but were recognized and commented upon. On the Tarawa strike, for instance, Commander of the Fifth Fleet commented on the fact that *Indianapolis* noon fuel reports showed an average consumption of 10% less fuel than did the reports of the other four heavy cruisers present. After the battle, Com. Fifth Fleet asked all ships present how much fresh water could be given to the 12 L.S.T.'s present, all of which were out of fresh water. The only vessel present which volunteered to donate fresh water to the L.S.T. group was *Indianapolis,* which pumped 120,000 gals. of fresh water to the 12 L.S.T.'s without the necessity of imposing "water hours" during or after the operation. After the Fifth Fleet struck Pellau and Yap, it was necessary for all ships present except *Indianapolis* to fuel. She still had 26.5% of fuel aboard upon arrival at base. When it is considered that the service force supporting this strike contained 16 tankers protected by C.V.E.'s, C.A.'s and D.D.'s had all of the ships present operated at maximum efficiency, the fuel requirements, and consequently the logistic support, could have been materially reduced.

By the methods outlined above, the writer's calculations indicate a total saving on the three ships named of 1,725,000 gals. of fuel oil or 41,070 bbls. during a three-year period.

It is probable that our national petroleum reserves and refining capacity are theoretically sufficient to supply the defense forces during a possible World War III. It is doubtful, however, that we have on hand the pipe line, tank car, tank truck and seagoing tanker equipment to deliver the vital petroleum products in the quantities needed, throughout the world. It would, therefore, seem important to practice every possible economy in the use of petroleum products. Only by so doing can we assure sufficient supply of fuel and lubricants when and where needed.

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ELECTRON TUBE RELIABILITY

ACKNOWLEDGMENT

MR. E. FINLEY CARTER, Vice President in Charge of Engineering, Sylvania Electric Products, Inc., is the author of this article, which appeared in the November-December 1951 issue of "Signal."

Many present day applications of electron tubes, particularly in the military field, call for a degree of reliability in tubes which has not been generally available. In view of the many millions of tubes made over a period of years by a variety of manufacturers, this may be somewhat puzzling. However, there are well founded reasons for this condition which are analyzed here. Also, some suggestions are made to both users and designers of tubes for obtaining the required degree of reliability for the job at hand.

The electronics industry is in a transitional period which started before the beginning of the second world war. There is no end in sight of the increasingly complex demands upon electronic circuitry and with greater complexity there is required even greater reliability.

Many of us grew up in what might be called the "radio industry." The highly competitive nature of the radio receiver phase of this industry was and still is reflected in its products. Ingenuity has been directed toward designs suitable for mass production where, because of the quantities involved, profit margins have been dependent upon savings of pennies per set.

Absolute perfection, even if attainable, does not constitute most economical design for amusement and entertainment service. There is a delicate balance between the cost of manufacture and the cost of field service. It is considered good competitive practice to design close to the edge as long as cost of field service in dollars and in goodwill is less than the increased cost of a more conservative design. Inconvenience, rather than failure of a mission or loss of life, is the penalty of malfunction. Even so, the advent of television, with the greatly increased number of components in a television receiver and therefore the higher statistical probability of failure, has dictated general tightening of standards.

The war and the performance requirements of military electronic equipment brought to all of us, equipment and component manufacturers alike, problems of a new order of magnitude. No longer is mere inconvenience, or even loss of goodwill, the price of failure of a tube or other component. The grim purpose of war must be served. The enemy plane that is missed because of such a failure may be carrying a bomb which will bring great destruction to one

of our cities. An important mission may be aborted because of a seemingly minor failure. The lives of our men and vast sums invested in military equipment are being bet on the dependability of vital electronic gear. Nor is such dependence upon electronics for life and safety limited to military equipment. One cannot fly across the mountains or oceans or be stacked in the clouds over a busy airport without having to rely upon the proper functioning of apparatus for which we, as electronic engineers, are responsible.

This is a heavy responsibility, and I am sure we all want to take adequate precautions to insure dependability in the design and production of such equipment.

Our most immediate need is greater knowledge and better understanding of the task at hand. We must discard some of the habits and practices which are acceptable in a competitive entertainment economy, but dangerous if carried over into the design of military, navigational, or other vital equipment. We must thoroughly analyze and evaluate the more difficult requirements and come up with a well integrated solution. To do this, there is a need for dissemination of knowledge of the functions to be performed by the components that go into electronic systems. I believe there is much that manufacturers of vacuum tubes can do to acquaint users of what tubes can and cannot be expected to do, and how they might be used most effectively for the purpose at hand. In order to do this well, a close liaison needs to be maintained between the equipment designers and the electron tube engineers so that a thorough understanding of the application as well as of the component itself may result.

Too often an electron tube is considered as just a component, and it is not fully realized that it is a very complex system in itself. Practically all of the known physical sciences are called on in the production of an electron tube, and still much reliance must be placed upon the art of making and processing it. The variables are so great that statistical analysis, much like that employed by the life insurance actuary, is required to evaluate the probabilities involved in the production and application of these devices. It is well known that both human beings and tubes suffer from a small, but significant mortality in early life. In both cases if life continues past the early critical period, the chances of a fairly long life are improved. Electron tube engineers are making steady progress in reducing early failures in tubes, just as medical science is steadily reducing infant mortality, but the stage has not yet been reached in either case where early mortality can be ignored. Just as there is human mortality by accident, by epidemic and through ultimate old age, so are vacuum tubes subject to failure because of other defective components, because of contamination, because of physical weakness and because of old age. Furthermore, vacuum tubes can be damaged beyond repair by overwork or overload just as an engineer, a salesman or an executive in the electronic business can be. It is interesting to note the great similarity between life data accumulated on a relatively large population of tubes tested over a period of time compared with an actuarial curve on human mortality taken from insurance tables. You will see the striking similarity that has been noted in Figure 1.

Figure 2 shows the rate of failure curves for tubes operated under normal life test conditions. I would like to point out the fact that the majority of early failures are due to mechanical defects. The percentage of mechanical failures per 100 hours reaches a low point early in life and does not rise much for the remainder of life. Failures due to gas and air increase slightly during life as do failures due to deterioration of perform-

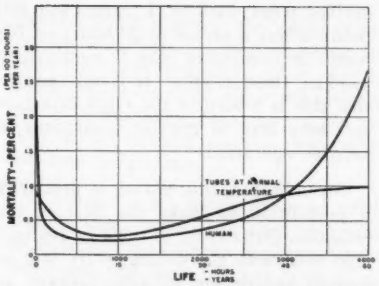

Fig. 1—Mortality curves for humans (1941 tables) and subminiature tubes having special attention for reliability.

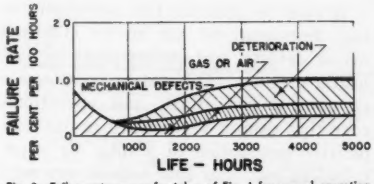

Fig. 2—Failure rate curves for tubes of Fig. 1 for normal operation. Mechanical defects are chief cause of early failure.

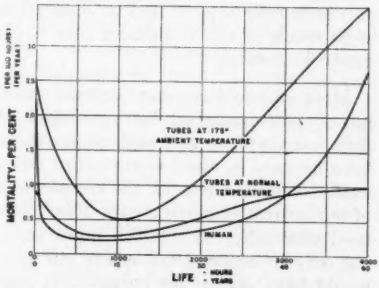

Fig. 3—Mortality curve of tubes operated at 175 degrees C. added to curves of Fig. 1. Failures are considerably increased.

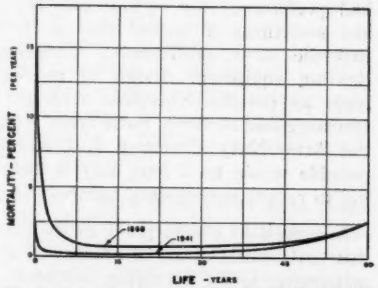

Fig. 4—Comparison of human mortality curves of 1868 and 1941. Great improvements, especially in infant mortality, were made.

ance characteristics. In many cases tubes are operated at high ambient temperatures and it is interesting to see how this affects the rates of failure for various reasons. Figure 3 shows the mortality curve for tubes operated at an ambient temperature of 175 degrees Centigrade compared with the curve for normally operated tubes and the human mortality curve. These data were taken on subminiature tubes which have received considerable attention for reliable operation. They represent what we can expect from such tubes at the present time.

Figure 4 illustrates the improvement in human mortality tables used by the life insurance companies. We see that there has been a very great improvement in early deaths during these 73 years due to advances in medical science. We can expect the same kind of results on early life of electron tubes if we apply concentrated effort to the problem. The support given by fundamentally interested tube users will necessarily determine the time when we obtain significant results.

Realizing that the best figures so far obtainable on the rate of tube failures run around two-tenths of one percent for 100 hours, and also that this is considerably better than can be expected for the average tube made to meet entertainment standards, what can be done to design equipment that will operate with the required degree of reliability? The first thing we must do is to utilize what we already know to the fullest possible extent. Tubes for vital applications should by no means be procured on the basis of price alone. Other stipulations relative to quality standards must be carefully considered.

It must be realized that although certain tests can be set up to eliminate major defects, real quality must be *built* into a product. This may require quality control procedures and operational care that cannot be justified in the competitive production of a tube for entertainment use. For that reason, one must expect to pay higher prices than would result on a low competitive bid to supply regular stock tubes. This fact has not been fully appreciated in connection with much of the equipment that is already in service.

Most of you have seen systems made up of units supplied by a number of different suppliers and perhaps you have been amazed by the assortment of tubes used. A breakdown of the complement of one system employing over 1000 tubes used four different rectifier types varying only in minor detail where one type would have served the purpose. It also had within it four or five variations of medium mu duo triodes and so on. It was obvious that individual suppliers had preferences for certain tube types and sometimes it seemed that no two had the same preferences. Certainly limiting equipment design to as few types as possible consistent with performance and choosing those types from the Army-Navy Preferred List where possible would go a long way in helping to reduce unnecessary failures.

Inasmuch as events point to the fact that early failures can be eliminated by preburning under operating conditions, there is an increasing tendency to specify that tubes used in vital sockets be given a certain period of burning under full rated conditions before inspection. A 50-hour burning period has been generally specified although there is nothing sacred about this period. Recommendations are being made now that a more realistic approach be taken by establishing a specification calling for the burning period to be sufficiently long to bring the failure rate down to some prescribed point, such as, 1 percent per 100 hours where a period of 20 hours or 100 hours or even more may be required to produce these results. It is my opinion that this is a step in the right direction and may lead to greater assurances of reliable operation.

As indicated, this testing is primarily a precaution to make the best of the situation that exists. It must be realized that even with the testing, there will be certain percentage of tube failures as there no doubt will be of other components. Therefore, real consideration should be given in design to add additional factors of safety, first by conservative use of tubes, and second by making allowances, wherever possible for easy and quick servicing of vital circuit elements.

In radio receiver design, it is common practice to reduce cost wherever possible and in doing this there is little allowance made for the safety factor in the operation of tubes. The maximum ratings are too often taken as the recommended operating conditions and little serious difficulty results. An **rf** or **if** amplifier, for example, is operated at a full 250 volts because that voltage is available. It may also be operated so as to depend only upon the AVC system and contact potential bias to keep the tube at about the rated current. As a result, these tubes may be operating at several watts plate dissipation where the functions they perform require them to amplify microwatts. It is not surprising then that vital equipment is often designed without taking advantage of the fact that plate and screen voltages could be lowered very appreciably for tubes performing such functions with very little sacrifice in gain and thereby appreciably increase factors of safety and extend the life of such tubes. Also, a thorough analysis of a circuit might show that very high transconductance values with the corresponding close element spacing may not be

necessary to procure the performance needed and that instead of limiting the gain by poor transformers, it may be more conservative to use a tube having lower transconductance, but considerably wider element spacing, with more efficient components.

I wonder if we would be in as much trouble today with 6J6's used in bridge or balance type circuits if electron tube engineers had been diligent in pointing out to the circuit designers the inadequacy of this particular design to serve the purpose. Many of you still probably do not realize the 6J6 has a single cathode on either side which is an independent grid and plate. In the conventional tube design, a slight deflection of the cathode from one side of the grid brings it closer to the other side of the same grid so there is some compensation. However, a slight deflection of the cathode of the 6J6 produces just the opposite effect on one-half of the structure to that on the other half so that the effect of variations is multiplied by two.

Now for a minute let us just in order to appreciate what might happen in a 6J6 look at it on a 1000 to 1 scale as shown in Figure 5. On this basis, the cathode might be considered as a flattened tube 33 feet long and 2½ by 10 feet in cross section with the walls about 2 inches thick and supported about 2 inches from grid structures on top and bottom. Furthermore, let us remember that this tube would be mounted on its structure at room temperature, but under operating conditions it would be heated to a cherry red heat. With due allowances, we may now apply the same shock and vibration that is applied to a tube in the type of applications we are considering. If we remember that a variation of only one-half inch would change the spacing on one side to one and one-half inch as against two and one-half inches on the other, we can readily appreciate the parameters with which we are working. Good conservative design, to my way of thinking, would employ either separate triodes or a duo triode of double barrel construction with separate cathodes so that individual cathode resistors could be used and thereby operate in a direction to compensate for variations rather than to magnify them.

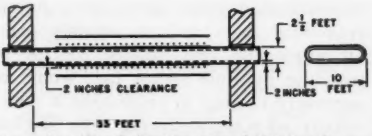

Fig. 5—Type 6J6 with dimensions increased 1000 times for easy comparison with familiar structures. Slight deflection of cathode produces large unbalance of characteristics of the two triode sections.

Time does not allow the citing of many examples that could be brought up which would make for a greater factor of safety in the utilization of electron tubes. I would like, however, to make this point which was brought out by a man not active in the tube field. He asked the question. "Why do you speak of reliable tubes? You seldom hear of a reliable beam or strut nor do you differentiate bridges by speaking of them as reliable or non-reliable bridges. Do not electronic engineers design factors of safety in their circuits just as a bridge or a building engineer would in his design?"

What I have tried to do is to make a plea that we make the best use of the facilities at hand while striving to make still greater improvements to meet the ever-increasing requirements placed on electronic devices. Much work is now in process to improve electron tube reliability both by the application of sound quality control techniques as, for example, in the ARINC approach and through the improvements of designs incorporated in special ruggedized and subminiature tubes.

In the development of the subminiature series of tubes, considerable long term thinking was applied to holding designs to a minimum number of basic types and

to concentrate effort upon being able to reproduce them and to simplify overall processing and quality control by avoiding multiple setups that would be necessary to keep in production a wider variety of tubes differing only slightly in characteristics. I shall not dwell upon each specific type, but do want to emphasize the point that even though in some cases it may be necessary to design more conservatively, a goal of high dependability can most readily be reached if we can avoid letting these few basic types be multiplied into a lot of types that can be justified only because their introduction might eventually take a few cents of cost out of the circuit. It is believed that better performance will be achieved as a result of production studies that are now being made on more uniform production runs. Much emphasis is being placed upon the application of sound quality control techniques in their manufacture.

A further look at subminiature tubes will disclose that they have been designed primarily for low voltage operation. Some of them were designed for 26 volts on plate and screen and others for 100 volts. Again may I point out where tubes are used for amplifying low level signals, it is not essential that their plate voltage supplies should be high. When using lower voltages, there is not only advantage gained in improving the tube reliability, but there is also allowed room for additional factors of safety on other circuit components. I hope these factors of safety will be utilized as such and not be used as justification for taking chances on appreciably lowered condenser and other components ratings.

There is a third step to any progressive program and that is the one not yet achieved. After eliminating tubes that were not designed to meet the high requirements for dependability now dictated and after thoroughly evaluating improved tubes and utilizing them as effectively as possible through design considerations and optimum operational conditions, we realize we are still short of the desired goal. This is particularly true when it is evident that requirements will become increasingly difficult. Because of this, considerable thought has been given to a more ideal approach which has not yet been achieved, but which can result only after thoroughly analyzing and evaluating the good and bad factors of existing techniques and eliminating the bad while improving upon the good. We know, for example that the conventional grid structures with side rods supported in mica spacers are not ideal. Furthermore, there are limitations to tolerances that can be maintained in present tube designs and too much dependence is placed upon the human element in the assembly and welding of the present structures. Attention is therefore being turned to a structure incorporating some of the strong points of types like the 2C36 and 2C37 which have peripherally supported grids and other elements with suitable spacers all forming a part of one rugged structure. Design attention is being given to the improvement of uniformity by eliminating much of the hand labor and using an increasing number of machine operations. It would be well in the development of such a new approach if circuit engineers would give serious thought to designs which would allow for a very minimum number of simple basic tube types so that machinery could be set up to turn out tubes with great uniformity. This can be done only if large runs can be made of a few types rather than a multiplicity of setups to take care of variations.

This is much different from the approach made by the Germans when they manufactured just a few tube types for many uses. They used a complex tube of many electrodes and connected the electrodes together for simple circuit

design. While they did achieve standardization, they were still plagued by many troubles inherent in the use of complex tubes. By using simple tubes many of the difficulties can be eliminated.

I would suggest, for example, that real ingenuity be directed toward finding how universally a well designed grounded grid type triode could be applied to radio amplification, audio amplification, mixing, oscillators, diode and triode detectors and the like. It will be well worth the effort spent if a tube that is highly rugged and reproducible as well as flexible in application results.

There is another promising development on the horizon which may contribute substantially toward improvement of reliability though it is still a little early to talk much about it. This is the application of semi-conductors to rectification, detection and amplification. With the development of the junction type germanium triode there is justification for increased optimism. The full possibilities of such applications can be realized, however, only through the willingness to develop circuit techniques which will humor these new tools. As a matter of fact, I suspect that in our efforts to utilize solid state devices most effectively, we may awaken to the fact that there are also many things that can be done with a good grounded type triode that we have never seriously investigated before because of the availability of multielement tubes that still have their excellent points but which, nevertheless, may not contribute to circuit reliability.

It will bear repeating that lack of reliability in electron tubes is both a cause and an effect of poor system reliability. A better knowledge of the almost human vagaries of a given population of tubes, the probabilities of failure and the need for factors of safety in design will all pay good dividends in equipment reliability. We must all make a concerted effort to make the best possible selection and the best use of available tubes while striving to simplify and improve tube designs and to use such new tubes with due allowance for safety factor.

The panel on electron tubes of the Research and Development Board has gotten under way a project of considerable magnitude to investigate the many factors involved in reliability of electronic systems and to determine the most effective action to be taken. We hope that in the not too distant future we will not be talking of reliable electronic equipment and components. Such reliability will be taken for granted as it is in steel beams and similar things.

While this is being done, our efforts should be redoubled to design tubes which will eliminate known weaknesses. This can be done most effectively through close cooperation with set designers whose ingenuity is employed to work out designs requiring the minimum number of basic elements and here again I suggest real consideration be given to the wider application of grounded grid type triodes.

STRESSES IN PROPELLERS AND PROPELLER SHAFTING

ACKNOWLEDGMENT

This is a special staff article from "The Marine Engineer and Naval Architect" for January 1952. It outlines the propeller and propeller shaft problem and discusses the need for full-scale investigations similar to those conducted in the aeronautical field.

The value of electronic methods in engineering research is now well-established and they have proved to be of immense value, provided there is proper appreciation of their limitations and possible sources of error. Without this appreciation it is possible to obtain quite spurious results or, which is worse, half truths more dangerous than total errors. The time may come when electronic equipment is available for use by the inexpert but until then, except in the simplest cases, the handling of experimental programs involving the use of such equipment is best left to the specialist. This need for specialist supervision no doubt accounts for the mechanical engineer's preference for mechanical methods of measurement where these can be applied and, in the present state of the art, this preference must be respected. In many applications, however, electronic methods represent the only practical means for resolving immediate troubles and at the same time affording an insight into fundamental causes whereby design trends can be directed along more profitable channels. Probably the most spectacular rewards from the use of such equipment have been reaped by the aircraft industry where, for example, rapid progress in the design and construction of high-performance machines over the last fifteen years has been due in no small measure to the foresight and enterprise of the industry in pioneering the development and practical application of electrically sensitive resistance wire strain gauges and their accessories.

An American automobile engineer once declared that by the time a laboratory investigator had provided for all the conditions that occur in service he would find himself on the road with a complete motor car! Since not least of the special advantages of electronic methods is their adaptability for obtaining measurements from the individual parts of a machine while it is operating in service it is not surprising that these methods have become popular in almost every department of engineering development. The relevant literature contains examples of the use of resistance wire strain gauges in marine engineering and naval architecture, ranging from the investigation of hull reactions during launching to the determination of static and dynamic stresses in structural components such as rudder stocks,

boiler drums, intermediate shafting, and connecting rod bolts.

Among notable and authoritative contributions in this field are the papers presented in recent years by Dr. Dorey, Chief Engineer Surveyor to Lloyd's Register of Shipping. His most recent paper,* on the subject of stresses in propeller and propeller shafting is therefore worthy of more careful consideration than we were able to give it in the editorial comment in the July issue. As Dr. Dorey himself remarks, the continual failures and renewals of tailshafts in Liberty and similar war-built steamships accentuated by incidents such as that of the *Castledore,* which recently led to the loss of the ship and the near-loss of her crew when in ballast condition, inevitably focus attention upon the need for improved knowledge of the stress conditions which arise in service. The serious nature of the problem, which is not confined to American-built tonnage, is indicated by the statistics quoted by Dr. Dorey from an analysis of data at April 1951 on tailshaft renewals in war-built tonnage now classed with Lloyd's Register. Of the 653 shafts considered in Dr. Dorey's review the renewals from all causes, including at owner's instructions, numbered no less than 288 or 44 percent, and the average life of the individual shafts was just over 4.5 years.

Authorities on both sides of the Atlantic have given a great deal of thought to this problem and we ourselves have referred to it at some length on several occasions. Some very sensible opinions have been expressed and certain practical suggestions for improving the situation have been put forward, but until now there appears to have been no definite proposal for the initiation of an experimental program aimed at uncovering the very roots of the problem. It is therefore to the credit of Dr. Dorey and his co-workers at Lloyd's Register that they have not only come forward with a proposal to attack the problem of determining the stress conditions in the propeller/tailshaft assembly under service conditions at sea by means of resistance wire strain gauges, but they have proved the practicability of the project by carrying out some exploratory tests in which the stresses in the propeller blades of a 32-ft. cabin cruiser were successfully recorded.

AIRCRAFT PARALLEL

In this connection the aircraft industry was confronted by a similar problem when, during the late 1930's, there was a general trend towards metal-bladed airscrews for high performance aircraft. With the general use of metal blades, airscrew blade failures began to occur in rather serious numbers even in applications where the screw was operating at quite nominal steady stressing conditions. The problem was immediately attacked by initiating (1), a comprehensive program of research on methods of recording blade stresses in service which culminated in the development of the electrically-sensitive resistance wire strain gauge as we know it today; (2) a complete revision of the theory underlying vibration of an airscrew/shaft assembly; (3) a comprehensive program of fatigue testing of full-scale components to investigate material properties and methods of improving fatigue strength by design modifications and surface treatments. This work soon paid handsome dividends for not

* "Stresses in Propellers and Propeller Shafting under Service Conditions," by S. F. Dorey, C.B.E., D.Sc., F.R.S.; read before the International Conference of Naval Architects and Marine Engineers, Newcastle, June 5, 1951.

only was the succession of failures completely arrested, but airscrew strength, reliability and performance were greatly increased, with an appreciable reduction of specific weight.

We do not suggest that all the experience and findings from airscrew research are directly applicable to the marine problem but we do consider that some measure of cooperation between the two industries could hardly fail to be beneficial in directing experimental work in the marine field, along channels most likely to yield speedy profitable results.

PROPELLER TAILSHAFT CASUALTIES

Dr. Dorey refers to the need for further light on such vital problems as the stresses induced in propeller blades by torsional and axial vibration; he also mentions the influence of aperture fairing and blade clearances upon propeller and propeller shaft vibration, including whirling and "singing" phenomena; and the stresses induced in propeller blades and propeller shafts under conditions of partial screw immersion and when racing are also discussed in his Newcastle paper. Overshadowing all, however, there is the urgent problem of the high incidence of propeller tailshaft failures and it is therefore rather surprising to learn from Dr. Dorey's paper that, because the majority of tailshaft failures occur in single-screw ships with balanced type rudders, it may be necessary to await the public-spirited cooperation of an owner, or organization, willing to afford facilities for experiments using a hollow-bored tailshaft with slip rings at the inboard end. The provision of a hollow tailshaft for work of such great potential value would seem to be a small matter and one should surely be forthcoming from the industry when it is required.

In the meantime a considerable literature on the subject of tailshaft casualties has accumulated and in a well-presented summary of the present situation Dr. Dorey concludes that while there is sufficient evidence to show that adequate ballasting for the avoidance of racing and its attendant vibratory evils is an important factor in prolonging the life of a tailshaft, there seems little doubt that other influences also enter into the equation both as regards design, material, machining and fit of the propeller assembly. Of these he considers the following worthy of special attention.

> Badly fitted propellers and keys and inadequate fillet radii at the roots of the shaft keyway—the fillet radius should preferably be not less than ¼ in. for a 15-in. shaft; key-retaining bolt and the end of the key itself too near the top end of the cone—the end of the key might with advantage be stopped 2 to 3 in. further aft; leaky rubber rings at the large end of the cone—the fitting of an extra seal of the external-gland-type, *additional* to the normal arrangement, would be a cheap insurance against careless workmanship; leakage along the shaft from the small end of the cone—recent American experience suggests the need for sealing the annular space between the propeller boss and the shaft threads, as well as the clearance between the top of the key and the bottom of the propeller keyway, with a suitable compound before tightening the propeller nut; forging ratio of the shaft—although recent tests have not confirmed the suggestion that a reduction of forging ratio from 5 to 1 to 3 to 1 might have adversely affected the notched-bar impact resistance of the shafts it is known that all the major forges in this country prefer to adhere to the older prac-

tice of a 5 to 1 ratio for this class of shaft, and it would therefore seem prudent for owners of these types of vessel to specify the 5 to 1 ratio when ordering replacement shafts.

In addition to these important aspects of screwshaft casualties, Dr. Dorey describes a number of problems encountered in the course of work at Lloyd's Register where torsional or bending stresses were the predominant influences. Direct stresses in the longitudinal direction are not considered because trouble from this cause is only likely to arise in merchant ships where the thrust foundation is unusually elastic and where the revolutions per minute are fairly high, as in passenger service. Moreover, experience has indicated that the magnitude of longitudinal vibration stresses in propeller shafting is relatively unimportant, the most objectionable features of such vibrations being the possibilities of trouble from wear in reduction gears, turbine flexible couplings, and stern glands and bearings; loosening of thrust block seat connections can also occur. Another possibility, not mentioned by the author of the paper in question, is that of appreciable supplementary stresses in the propeller blades.

TORSIONAL STRESS PROBLEMS

With regard to torsional stresses several examples are given showing the paramount importance of design-stage calculations of torsional vibration characteristics as the best form of insurance against trouble from this cause, and, as Dr. Dorey points out, this policy of enlightened self-interest has been repeatedly and insistently advocated by Lloyd's Register, where the necessary rule requirements have been laid down since January 1944. The examples have been well-chosen to illustrate the need for taking into account all possible operating conditions. Thus in cases where service conditions demand frequent maneuvering and operation at reduced speeds, e.g., tugs, trawlers, coasters, and river vessels operating in areas of fast currents and canal locks, it is important to avoid high transient stresses over the whole speed range from idling to full rpm. All major criticals should be placed well above service speed or, if this is impracticable, the speed range above about 80 percent of service revolutions should be maintained clear of important criticals, with properly marked barred speed ranges where required elsewhere.

The examples also indicate the dangers of making changes in shaft dimensions without first investigating the effect of such changes on torsional vibration characteristics, preferably with the aid of torsiograph measurements from the original installation. In many cases the effect of attempting to strengthen a shaft by an arbitrary increase of dimensions may only result in weakening it.

Referring again to screwshaft casualties it is emphasized in the paper that our knowledge of the effects of heavy weather on the torque loading of propeller shafting needs further extension if casualty rates are to be minimized. Measurements already made suggest that in motorship installations with the engines racing freely, and even when shut in on account of heavy weather, the measured torque variations may be sufficiently great to cause torque reversal. In reciprocating steam engines the much lower inertia of the engines coupled with the reserve of steam in the hp. receiver after cut-off, inevitably leads to considerably higher speed surges when pitching in a seaway. Instantaneous speeds up to double the normal service rpm have been measured in typical installations not fitted with governors, and even when well linked-in and with efficient governing

speed rises up to 50 percent are easily possible.

The most dangerous effect of excessive speed variations brought about by loss of hydrodynamic load on the propeller is the possibility of running into resonance with third or second order major critical speeds without the protection of propeller damping. These two orders are particularly objectionable because they are mainly inertia-excited and their magnitudes therefore increase with the square of the rpm.

In steam turbine installations, when pitching, the amount of the propeller torque variation which is applied to the propeller shaft may be particularly severe. In fact, Dr. Dorey reproduces calculations which show that practically the whole of the torque variation due to pitching is applied to the propeller shaft in the case of turbine installations, compared with only about 25 percent with steam reciprocating machinery. The explanation lies in the fact that with turbines the propeller inertia, referred to propeller shaft speed, is small in relation to the inertia of the turbines and gears, whereas it is large compared with the inertia of a reciprocating steam engine and in the latter case the propeller acts as an inertia shield. The practical significance of these findings is perhaps reflected by the fact that in the statistics of screwshaft casualties quoted by Dr. Dorey, the geared-turbine Victory class has the worst record in terms of percentage of tailshaft renewals, namely 63.3 percent compared with an average of 42.5 percent for the wartime vessels with reciprocating steam engines. Incidentally, it is of interest to note that analysis of the Victory class record shows a renewal rate of 75 percent for those ships carrying 428 tons of ballast in the tunnel tanks, compared with a renewal rate of about 60 percent for those having 1,684 tons of tunnel ballast.

To complete the series of examples on torsional vibration there is a description in the Newcastle paper of the failure of the propeller of a small oil-engined coaster which shed a propeller blade on three separate occasions. Subsequent calculations showed that the service speed coincided with a major one-node torsional critical speed. Although the shaft stress at resonance did not greatly exceed the acceptable limits, the vibratory amplitude at the propeller was abnormally large in relation to that at the engine, since the engine was fitted with an unusually heavy flywheel. As a consequence heavy vibratory inertia torques were set up at the blade roots and the resulting corrosion-fatigue conditions were sufficient to cause rapid failure. This example illustrates the wisdom of reducing vibratory *torques* to a minimum, even where shaft stresses may be moderate, since the resulting inertia torques applied to keyed connections and propeller assemblies may lead to loosening or even more serious consequences. Other examples of this effect have been found in the fastenings of the laminated core plates in generator armatures where the torsional vibration stress in the relatively stiff armature shaft itself has been quite low.

BENDING STRESS PROBLEMS

The evaluation and measurement of bending stresses are both inherently more difficult problems than in the case of torsional stresses, and it is in this field that the limitations of mechanical methods of measurement are most pronounced and the advantages of electronic methods most marked. The bending stresses arising in propeller shafting are, broadly speaking, derived from two causes, namely, changes in bearing alignment and stresses caused by hydrodynamic and inertia forces acting upon the propeller.

Dr. Dorey considers it is probably true that the problem of bearing alignment relates more to bearing performance than to shaft stress. Thus it is a common experience to find that under ballast conditions certain bearings in the shaft tunnel will tend to run hotter than others, while under loaded conditions the temperature distribution may be completely different. In some ships this variation has been so extreme that it has been necessary to alter the level of the aftermost plummer block when changing from loaded to ballast condition, and *vice versa*. A description is given of an ingenious and easily manipulated strain gauge, developed by the engineering research department of Lloyd's Register, to facilitate the initial adjustment and maintenance of bearing alignment. This gauge is of simple construction, high sensitivity, and provides a direct measure of cyclical bending strains in the shafting from which the misalignment of the various bearings in both the horizontal and vertical planes can be derived. It can be applied at any position along the shafting, is held in position magnetically, and its use does not require the "breaking" of the couplings.

VIBRATION OF THE PROPELLER/TAILSHAFT ASSEMBLY

The problem of determining the response of a propeller/tailshaft assembly to disturbances originated by propeller action both under normal service conditions and under the severest weather conditions likely to be encountered is probably one of the most complicated and difficult tasks in this field of study. This is because of the large number of possibilities of resonance. Although many of these possibilities have little practical significance there is a feeling in some quarters that modern design trends with regard to after body shapes, aperture characteristics and rudder arrangements have considerably multiplied the number of practical possibilities.

The only way of resolving the problem is to determine which of the many possibilities are important by a comprehensive series of full-scale strain gauge tests under every type of service condition. It would appear that there is now available sufficient experience on the necessary instrumentation and test procedures to enable this work to be initiated. As we have already mentioned, tests of this type were introduced in the aircraft industry many years ago and are now a standard part of research and development programs. A considerable amount of knowledge has accumulated, much of which might be of value in reducing the cost and time required for a parallel marine investigation.

We have prepared the accompanying diagrams from information provided by research on airscrews, since they serve to illustrate the great complexity of the propeller/shaft problem and will doubtless be of general interest. Fig. 1 shows one of the possible families of propeller blade vibrations, namely, vibration of a flat elliptical plate fixed at one end of the major axis. Broadly speaking there are two main possibilities, vibration in a flatwise or flapping direction with various numbers of nodal lines running across the blade (0/0, 0/1, 0/2, etc.), and vibration in a torsional sense with various numbers of nodal lines running along the blade (1/0, 2/0, 3/0, etc.). Each individual mode can be classified as an m/n mode, where m is the number of torsional nodal lines and n the number of flexural

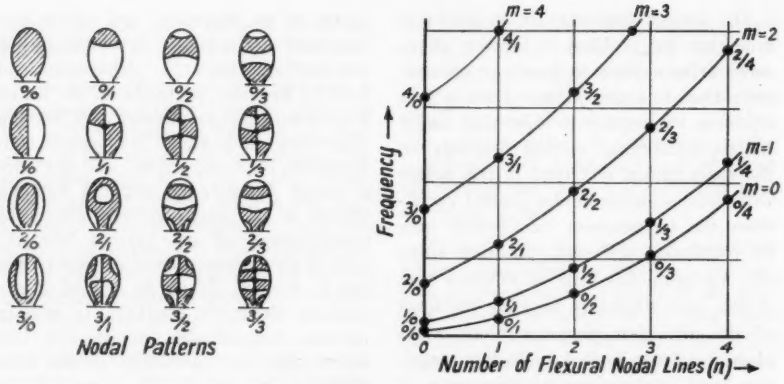

Fig. 1. Left: showing possible variations of propeller blade vibrations. Right: possibilities of combined flexural and torsional modes

nodal lines. The diagram shows that in addition to the simple torsional or flexural modes there are possibilities of combined torsional and flexural modes (1/1, 1/2, 1/3.....2/1, 2/2, 2/3, ...3/1, 3/2, 3/3, etc.). Nor is this the whole story, for where the frequency of one of these modes happens to be near that of another there is the possibility of cross-coupling, which results in a further multiplication of the possibilities of resonance. Furthermore, the diagram refers only to a simple laboratory experiment where the propeller blade has been idealized as a flat plate of uniform thickness. In the practical case the matter is much more complicated due to such effects as variation of thickness, curvature of sections, and the influences of gyroscopic actions, rotational speed, entrained water, and pitch setting.

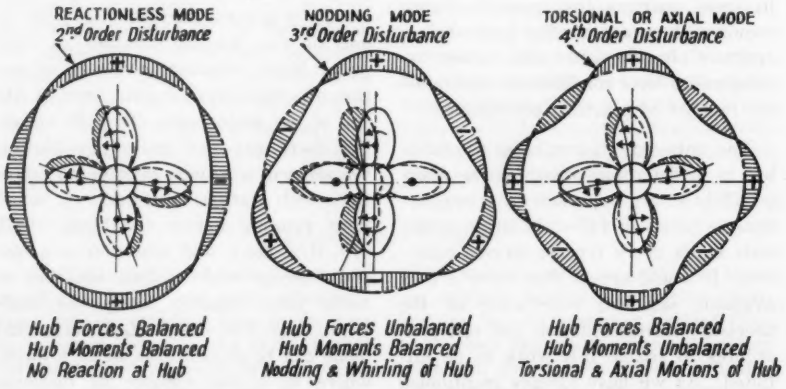

Fig. 2. The three types of edgewise vibration mentioned in the text

EDGEWISE VIBRATIONS

It must also be borne in mind that, in the practical case, edgewise as well as flatwise vibrations are possible, and that these are invariably closely coupled, while in addition to the fixed hub modes shown in Fig. 2 there is the possibility of rocking hub modes in which the root of each blade is not a nodal point. However, the main purpose of Fig. 1 is to show that even in an elementary case there are many possibilities of resonance, any one of which is liable to become a source of trouble given an appropriate excitation. The principal excitations are the various harmonic torque impulses originated by the engine; the different harmonics of the disturbed flow through the propeller disc originated by obstructions to the flow, variations of propeller immersion in heavy weather, the passage of blade tips close to the surrounding structure, and so on; and first order excitations originated by propeller mass or pitch unbalance, or by an oblique flow of water to the propeller disc (yaw excitation). Propeller pitch unbalance is a more potent cause of first-order vibration than propeller mass unbalance because a comparatively small change of geometrical pitch may cause a large change of the effective angle of attack. Yaw excitation may be present, for example, in multi-screw installations where the propeller shafts are inclined to the true longitudinal axis.

These various excitations produce, in general, three types of response in a propeller/tailshaft assembly, depending upon the number of propeller blades and the particular exciting harmonic under consideration. These three types of response are classified as torsional (or axial), nodding, and reactionless.

Fig. 2 shows this in a simple way. The torsional (or axial) mode causes flexural vibration of the propeller blades and torsional or axial vibration of the hub and shaft. The harmonic order numbers which excite this mode are the integer multiples of the number of propeller blades, i.e., K.n., where K is any integer and n is the number of blades. There are no impulses on the static parts (shaft bearings and the structure surrounding the propeller) except in the case of a thrust bearing which would experience axial impulses at the excitation frequency K.n.N., where N is the shaft rpm. The frequencies of the stress cycles in the rotating

Number of Blades	Mode	Excitation Order Number											
Three	Torsional	—	—	3	—	—	6	—	—	9	—	—	12
	Nodding	1	2	—	4	5	—	7	8	—	10	11	—
	Reactionless	—	—	—	—	—	—	—	—	—	—	—	—
Four	Torsional	—	—	—	4	—	—	—	8	—	—	—	12
	Nodding	1	—	3	—	5	—	7	—	9	—	11	—
	Reactionless	—	2	—	—	—	6	—	—	—	10	—	—
Five	Torsional	—	—	—	—	5	—	—	—	—	10	—	—
	Nodding	1	—	—	4	—	6	—	—	9	—	11	—
	Reactionless	—	2	3	—	—	—	7	8	—	—	—	12

TABLE SUMMARIZING THE VARIOUS POSSIBILITIES OF EDGEWISE VIBRATION FOR THREE-, FOUR-, AND FIVE-BLADED PROPELLERS.

parts (propeller blades and the individual fibers of the shaft) are also K.n.N.

The nodding mode causes flexural vibration of the blades and shaft and may also produce nodding or whirling motions of the hub on its overhung shaft. The harmonic order numbers which excite this mode are the integer multiples of the number of blades plus and minus one, i.e, $(K.n \pm 1)$. The frequencies of the stress cycles or impulses in the static parts are $(K.n \pm 1)\,N$, while those in the rotating parts depend upon the characteristics of any nodding or whirling motions which may be imparted to the hub.

In general, a propeller with n blades passing m fixed obstructions, or subjected to m pressure variations during each rotation, may experience nodding or whirling motions of the hub at nodding or whirling frequencies (n.m.N.), provided m is one of the orders $(K.n. \pm 1)$ capable of exciting a nodding mode. Thus, in addition to stress cycle frequencies of (n.m.N) the rotating parts may experience stress cycle frequencies of $(n.m.—1)N$ and $(n.m. + 1)N$ depending upon whether a direct or a reverse circular whirl is initiated. As a general rule, however, due to lack of symmetry in the stiffness or inertia of a propeller/shaft assembly the whirl is elliptical; and since an elliptical whirl can be regarded as composed of a direct and a reverse circular motion, there is the possibility of the rotating parts being subjected to stress cycle frequencies $(n.m. \pm 1)N$.

The reactionless mode produces no reaction at the hub and therefore no impulses in the static parts. The harmonic order numbers which excite this mode are those integer multiples which remain after account has been taken of the torsional and nodding modes. This implies that there are no reactionless modes in propellers having less than three blades. The frequencies of the stress cycles in the blades are the order numbers of the reactionless modes multiplied by shaft rpm. This mode of vibration presented a rather troublesome problem during the early development of four-bladed metal airscrews, since the absence of any reaction at the hub results in damping being confined to the blades themselves and this tends to produce increased vibratory amplitudes and stresses in the blades in this mode.

The above table summarizes the various possibilities for propellers having three, four, and five blades.

The foregoing brief discussion indicates the rather formidable nature of the propeller/shaft problem, at least in theory, and suggests that further progress towards enlightenment must await a full-scale investigation of the type which is now a routine experimental procedure in the aeronautical field. It may well be that the time has come when the need for this enlightenment justifies an effort at least comparable with that which has been expended upon the shaft torsional vibration problem.

MARINE STEAM OIL ATOMIZERS

J. F. HARVEY

THE AUTHOR

was born in Washington, D. C., on May 20, 1913. Upon graduating from Cornell University in 1935 with the degree of Civil Engineer, he was employed by The Babcock and Wilcox Company. In 1937 he was granted a year's leave of absence from that company to accept a research assistantship at Cornell University, on a fellowship of the American Welding Society, to investigate the effect of stress distribution on the fatigue strength of welded joints; at that time he obtained the degree of Master of Civil Engineering. He is presently an Engineer in the Marine Department of The Babcock and Wilcox Company, Barberton, Ohio.

Industrial oil burning, as it is known today, with single burners consuming up to 10,000 pounds of oil an hour, is a relatively new art. The ancients used mineral oil and its residues for their wick lamps, and for making fire-arrows and fireballs in warfare, but when the latter became obsolete, as the introduction of gunpowder increased the range of engagement, oil became primarily a lighting or lamp fuel, which condition prevailed up to the industrial revolution. Rapid expansion in industrial machinery required quantities of lubricating oil and the lighter distillates; hence, it was natural that the development and processing of petroleum should be toward this end. The heavier residues were a waste for which industrial oil burning offered an outlet if satisfactory burners could be devised.

The first practical solution was found in preparing the fuel for burning by pulverization with saturated steam. Although heavy fuels were used, this method of oil pulverization, or atomization, as it is commonly called, was from the first successful, and led in Russia to a widespread use of oil for merchant and naval vessels and locomotives. The use of steam as a pulverizing agent has not only a physical pre-heating and atomizing action, but a chemical soot-preventing one by virtue of its "water gas reaction," a factor which was, undoubtedly, responsible for a good measure of its success. The primitive forerunner of the steam atomizing oil burner was the Russian domestic house heating stove [1],* which consisted of a flat dish placed at the bottom of a stove, and supplied by a gravity oil feed.

* Numbers in brackets designate the references in the bibliography at the end of the paper.

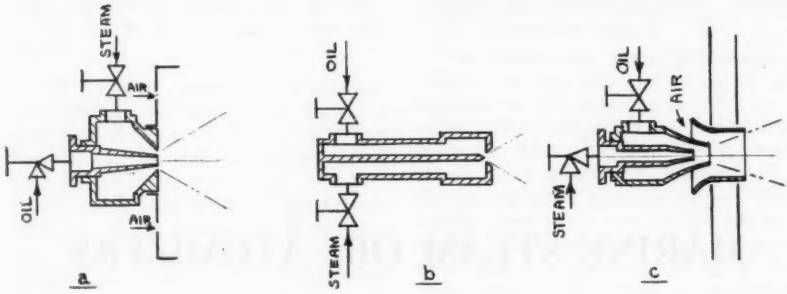

FIGURE 1 SCHEMATIC ARRANGEMENT OF EARLY RUSSIAN STEAM OIL ATOMIZERS, 1870-1900.

The oil was heated and evaporated by radiation from a refractory honeycomb placed above the flame. It is likely that combustion was poor when oil was burned alone, so water, probably perchance, was fed to the dish which threw up oil drops, as it spontaneously evaporated, and gave a less smoky flame. Successful experience with this crude forerunner of steam atomization was responsible in Russia for directing practically all future experiments for industrial oil burning purposes along the lines of steam atomization.

It is only natural that the first development of industrial oil burners should be toward their use on mobile power plants, such as required for ships or locomotives, in view of the storage and handling ease of oil as compared to coal. To this end the Russian stage was well set due to abundant petroleum resources, particularly in the region of the Caspian Sea, and by 1874 practically all merchant and naval vessels of the Volga River and Caspian Sea fleets were using oil for fuel. Steam atomizers were used exclusively, and fresh water consumption, which greatly hampered steam oil atomization adoption in most maritime nations, was no problem since the low pressure (50-60 p.s.i. gage) boilers were fed with salt water—the salt content being limited by blowing. It must be remembered that at this early date all boilers were of low pressure, had low heat release rates, and water conditioning was obtained solely by surface and bottom blowdown.

Figure 1a* shows schematically one of the first successful nozzle type steam atomizers used for marine service. Oil was admitted by a central tube which was surrounded by a steam chamber. The atomizing agent, steam velocity, is in contact with oil on the inside and on the outside with air on which it has an aspirating effect, thereby drawing air into the combustion chamber. This atomizer gave a flame shape which avoided flame impingement on the boiler surfaces of small marine boilers, for which it was widely used. Another type of atomizer that made its appearance at the same time is shown in Figure 1b, and consists of two adjacent slots, one

* Schematic sketches will be extensively used throughout for illustration purposes. The method of embodying the scheme in a practical construction is a matter of design detail.

for oil and one for steam. These openings can be made of various shapes, and orientation as required to give a flame shape suitable for the furnace. Adjusting the steam requirements for various rates with this type atomizer by a valve in the steam line is not usually satisfactory, since available steam velocity at the tip will drop with decreasing rates resulting in inferior atomization. Regulating the steam by changing the flow area of the exit orifice (by needle valves or the like, such as shown in Figure 4), in order to maintain full steam velocity at the tip at all rates for satisfactory atomization is theoretically superior to control by a valve in the steam line, but may give trouble in practice, due to seizure or carbonizing of the movable parts where exposed to the radiant heat of the flame.

Accompanying the development of marine steam oil atomizers were those for locomotives. First attempts soon disclosed that the atomizer could not merely be placed on the grates inside the firebox due to over-exposure to radiation which resulted in carbonizing (forming oil coke) both in the inside and outside of the atomizer nozzle with accompanying detrimental effect on the quality and spray angle of the atomized oil. This mistake led to the development of an atomizer of the type shown in Figure 1c, which was placed outside of the firebox. Provision was made for moving the steam nozzle axially within the oil nozzle for oil capacity control, while steam quantity control was by valve in the steam line. This atomizer differs somewhat from that of Figure 1a, in that the steam nozzle is located at the center with oil surrounding it, and that some degree of oil pulverization takes place within the venturi throat nozzle, thereby giving a limited degree of premix. This, and many of these early burners, used steam injection for supplying the combustion air supply, either for the total air supply, or when such made steam consumption prohibitive, as a primary air supply medium with secondary air by natural draft. This combined process of oil atomization and air injection promotes good mixing of air and oil. Atomizers of the type shown in Figure 1c were used extensively on Russian locomotives which, by the turn of the century, were all burning fuel oil with the exception of those in the coal regions and Siberia.

Simultaneously, in Great Britain, steam oil atomizers, in many respects similar in design to those used in Russia, were successfully developed and here the advantages of superheated steam for oil atomization were first recognized. Superheated steam gives a higher oil preheat, reduction in steam consumption due to its higher specific volume affording an equal velocity with less quantity, and a steady flame due to avoidance of water slugs as was frequent in the days of ineffective steam separators. British railway and maritime interests, notably the Admiralty, fostered extensive investigations and good results were obtained with several atomizers of the steam-oil type, Figure 2, and steam-air-oil type, Figure 3. Due to fuel oil cost, limited availability, and the economic opposition of the coal producing industry, the results of these experiments were not generally applied until about 1880. The first application was on locomotives, where objections to cost and availability were not too serious, since many railroads operated their own coal mines in connection with artificial gas plants and produced tar oil as a by-product.

The consumption of fresh water required by early steam atomizers prohibited their extensive use on ocean vessels, and in an effort to circumvent this objection, much attention was given to the development of oil-gas furnaces in which the oil was vaporized in a retort before being introduced to the furnace. This resulted in satisfactory combustion, but operating and mainte-

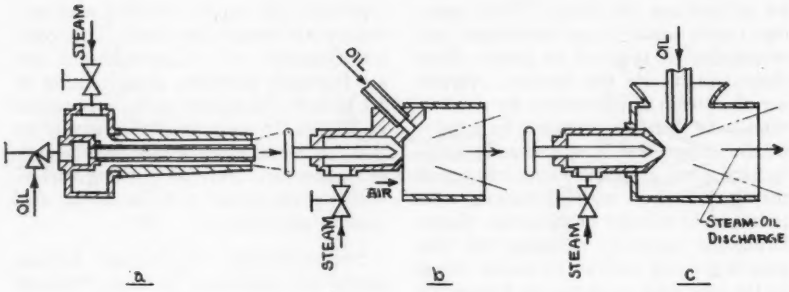

FIGURE 2. SCHEMATIC ARRANGEMENT OF EARLY BRITISH STEAM OIL ATOMIZERS, 1870-1900.

nance difficulties were encountered in the retorts which became coked with carbon. Experimental marine installations of both steam atomizing, and gas-oil burners, however, demonstrated that the evaporative rates obtainable with coal could be increased.

In France, during the same era, the development of oil burning was instigated by the problem of finding a use for the tar oil residue of gas works. Good technical progress was made in recognizing the value of minimizing air resistance, directing the air on the evaporating oil film, and using a minimum of excess air to maintain high furnace temperatures and combustion efficiency. Efforts to eliminate fresh water consumption included the use of compressed air, Figure 4, in lieu of steam as an atomizing agent, and it was found that even with the necessary addition of steam driven compressors, the operating range of destroyers was increased by conversion from coal to oil. Space, weight and maintenance problems limited the practical application of compressed air, and after early adoption of steam atomizers of the type shown in Figure 1b, the French Navy adopted a steam version, substantially as shown in Figure 4a.

In the United States, early experiments with industrial oil burners, starting about 1860, met with only limited success, and consisted mainly of efforts to vaporize the oil in retorts before introducing it into the furnace, or burn

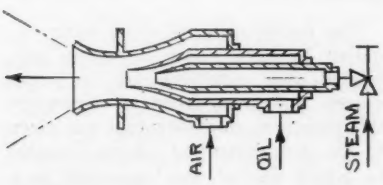

FIGURE 3. ARRANGEMENT OF EARLY BRITISH STEAM-AIR-OIL ATOMIZER, 1890-1900.

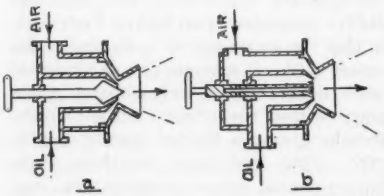

FIGURE 4. SCHEMATIC ARRANGEMENT OF EARLY FRENCH AIR OIL ATOMIZERS, 1880-1900.

it directly on porous refractory floors intended to act as wicks. It was found, as in other countries, that such devices readily coked-up. Occasionally, steam jets were used to assist in the furnace distribution of the combustible — a method that is still used today on many coal burning boilers. After these early failures, several steam atomizers, similar to those used in Europe, were developed and installed on a few locomotives, and west coast merchant vessels during the period 1890-1900. The first marine installations were on the west coast where coal was scarce and costly, and the discovery and development of the western oil fields provided a ready source of fuel.

In this country the Merchant Marine took the initiative in adopting oil as a fuel. The Navy, although undertaking considerable research and development with oil burners, did not adopt steam or compressed air oil atomizers for combat ships, as had the European Navies prior to the introduction of dynamic pulverization by straight oil pressure in 1902, or by this new form of oil atomization, until the advent of World War I.

At an early date it was apparent that the use of fuel oil for marine power plants offered promise of many great advantages:

1. Quicker bunkering.
2. Smaller bunker space.
3. Increased rates of boiler evaporation.
4. Smaller, lighter and more efficient boilers.
5. Increased power plant maneuverability.
6. Smokeless combustion.
7. Fewer personnel.

These considerations are particularly pertinent to naval vessels, and consequently, during the period 1890-1902, oil fired boilers were adopted by the European Navies, especially for vessels operating in home waters.

Prior to 1902 the widespread application of oil burners to marine service was seriously curtailed by:

1. The lack of an efficient method of burning oil without the use of steam or compressed air.
2. The scarcity of fuel oil and the lack of world-wide bunkering stations, such as existed for coal.

The first of these obstacles was by far the greater, since the steam consumption of the existing steam atomizers ranged upward from 3 percent of the boiler capacity. This was a great disadvantage to trans-oceanic ships, since the additional fresh water storage resulted in less cargo or magazine space. The use of compressed air, while not as satisfactory, required additional compressors and compressor capacity, both of which required increased initial and maintenance costs, and also larger engine room space allotments.

These objections to the use of oil burners were eliminated in 1902 by the introduction of dynamic pulverization of oil which accomplished atomization and distribution of the spray by means of high oil supply pressure. This new atomizer, which opened wide the marine field, was essentially one of constant capacity. A typical atomizer of the dynamic pulverization, or as more commonly called, straight mechanical pressure type, is shown in Figure 5. It consists essentially of a sprayer plate located at the tip of an oil supply barrel to which fuel oil is supplied under high

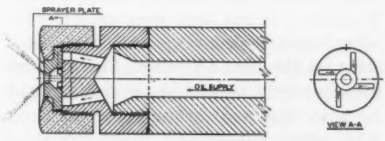

FIGURE 5. SECTION OF TYPICAL STRAIGHT MECHANICAL PRESSURE OIL ATOMIZER.

pressure. The sprayer plate contains a circular whirling chamber into which oil is fed through a multitude of tangential slots, thus establishing a whirling action. The oil is discharged, through a central circular outlet orifice, into the furnace in the form of a hollow cone of atomized oil. The capacity and the spray angle characteristics are largely determined by the relative size of the whirling chamber, and the inlet and outlet orifices [2]. Since the energy for atomization is derived solely from the oil supply pressure, there is a minimum pressure that will give satisfactory atomization. This has been found, by experience, to be approximately 75 p.s.i. for the usual Bunker C fuel oils at the preheated temperature required to maintain proper viscosity. The capacity of straight pressure atomizers varies approximately with the square root of the oil supply pressure. Thus, with 300 p.s.i. inlet oil pressure the capacity range within the limits of good atomization is only about 2:1. Greater capacity ranges require a manual change of sprayer plate and/or cutting burners in and out.

Soon after the introduction of mechanical atomization, steam atomizers retained only a limited field of special application on lake and river boats, and on dredges and tugs where rapid and frequent load changes warranted their favorable wide capacity range variation, and the loss of fresh water was not critical. World-wide distribution of fuel oil bunkering stations kept pace with the fuel oil requirements, and the conditions just described were essentially those existing in the marine field at the start of World War II.

THE PRESENT MARINE PROBLEM

It is rather ironical that steam atomizing oil burners, which were almost entirely superseded by the straight pressure oil atomizer for marine service because of their prohibitive steam consumption, should show such excellent promise as a possible solution to the present problem of providing wide capacity range burners capable of carrying all maneuvering and port loads in "cold" furnaces, with smokeless combustion, while burning poor quality residual fuel oil.

The size of marine boilers, and especially furnaces, has been decreasing steadily, resulting in higher furnace heat release rates and possibly temperatures. Therefore, it has been necessary to provide water-cooled walls and roofs, and some of the heat absorbing surface that was formerly placed in the boiler bank is now disposed around the furnace. This gives a so-called "cold furnace," relatively void of heat reflecting refractory, which often creates a difficult burning problem for a straight pressure atomizer operating at low maneuvering or port rates with corresponding low oil supply pressures. In addition, continued decrease in the space occupied by the heating surface has necessitated the use of close spaced bare, or extended surface, tubes in the convection passes which, if given the chance of poor combustion, act as excellent soot traps.

The loss of plant efficiency at low or maneuvering rates is not the real concern in marine service. Instead, it is the fire hazard arising from air heater or economizer soot accumulations resulting from poor combustion conditions, or the danger of furnace explosions resulting from loss of ignition and accumulation of raw oil in the furnace, which subsequently becomes ignited. To forestall this, steam atomization is resorted to frequently, with special consideration given to reducing the steam consumption over that required by the older steam oil atomizers.

COMBUSTION OF FUEL OIL

Industrial fuel oils are a mixture or blend of hydrocarbons, so-called because hydrogen and carbon are their principal constituents. The number of hydrocarbon compounds is huge and varies with the type crude, with the type of distillation or cracking process, and with the final burning process.

Crudes can be generally classified in three categories, depending upon their base—paraffin, asphaltic and naphthenic. Although ordinarily an entire field, or even a country, will produce the same base crude, it is not unusual to find all crudes in the same field.

Each of these crudes produce fuels suitable for burning. However, those with a paraffin base are more easily burned, while those with an asphaltic base give the most trouble. Generally, no selection is available to the designer or operator of marine oil burners, since ocean-going vessels must bunker in all parts of the world, and even the bunkering station serving lake and river boats are often supplied with fuels from different crudes.

Crude oil usually is not suitable, or offered, for industrial burning, because:

a. It generally contains both highly volatile and heavy residues, which make it difficult and dangerous to handle. (Viscosity is referred to by the word "heavy" in this case, rather than specific gravity.)

b. The design of fuel burning equipment (atomizer, air system, preheater, fuel service pumps) to handle such a range of volatility is impractical.

c. The lighter constituents, gasoline, etc., are premium products with a more lucrative market.

As a result, crudes are refined, which consists of separating them into fractions having the same boiling point range. These fractions range from the light distillates, such as gasoline, kerosene and lubricating oils, to the heavy residues used for industrial fuel oil. When this distillation is done at substantially atmospheric pressure, the products are referred to as "straight run"; however, in modern refining, this is usually only the beginning, for in order to secure greater yields of the premium light hydrocarbons, such as gasoline, the fractions heavier than this are "cracked" under high temperature and pressure, with or without a catalyst, to form new hydrocarbons, having both lighter and heavier fractions than the original, which, in turn, are separated according to volatility. Cracking, unlike simple distillation, changes the molecular structure so that crude oils yield much more of the valuable lighter fractions, and proportionally less of the heavy residual ones. Not only does the cracking process give less of the heavy residue which is used for industrial fuel, but it has poorer burning qualities, a condition which the designer must recognize and cope with.

The actual combustion process of hydrocarbons cannot be explained by simply equating the end points; that is, burning hydrogen and carbon to water and carbon dioxide [3]. The intermediate process between these end points is most complex, with the combustion process, represented by two extremes, occurring simultaneously in every hydrocarbon flame. These two types of combustion extremes are:

1. Blue flame, or aldehydeous combustion.

2. Yellow flame, or carbonic combustion.

In blue flame combustion (hydroxylation or aldehydeous combustion) the hydrocarbon molecules absorb oxygen to form peroxides, which further split up into aldehydes and water. The aldehydes then decompose to the final combustion end point of CO_2 and H_2O,

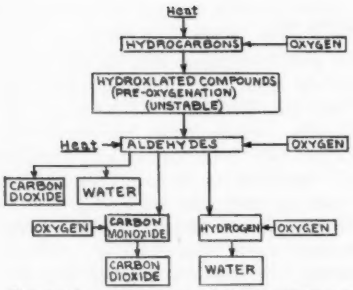

FIGURE 6. COMBUSTION OF HYDROCARBONS BY THE ALDEHYDEOUS OR BLUE FLAME PROCESS

though the process is not a direct or simple one, Figure 6. Under this form of combustion, uncombined carbon does not exist during any phase of the combustion process, hence incomplete combustion is not characterized by soot formation, but by invisible acrid vapors usually containing formaldehye, an intermediate product of blue flame combustion.

In yellow flame, or carbonic combustion, the hydrocarbons first decompose or crack into lighter hydrocarbon compounds and/or directly to carbon and hydrogen, and thence to the end products of CO_2 and H_2O. In this type combustion, uncombined carbon exists during a phase of the burning; consequently, formation of soot and smoke are possible if combustion is not completed, Figure 7.

These two types of combustion can be illustrated by burning illuminating gas, a hydrocarbon, in an atomsphere of air to produce a yellow flame, Figure 8a, and then reversing the procedure by burning air, so to speak, in an atmosphere of gas to produce a blue flame, Figure 8b. This difference in flame behavior can be explained much as follows. The flame center in each case is exposed to high heat radiation converging from all directions. When gas is present in this central zone, it cracks under the high temperature to form

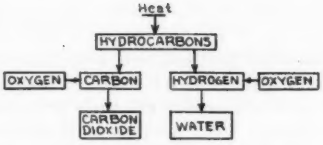

FIGURE 7 COMBUSTION OF HYDROCARBONS BY THE CARBONIC OR YELLOW FLAME PROCESS

particles of solid carbon which are set glowing, Figure 8a. Final oxidation takes place as these carbon particles pass through the flame front, hence, it is paramount that satisfactory burning conditions be established and maintained during this phase of the combustion process. If this is disturbed, due to poor air-oil mixing, soot and smoke will result, while if a relatively cold surface, such as a boiler furnace wall or tubes, is contacted, carbon deposits will build up. When the highly heated flame center is non-decomposable air, Figure 8b, the surrounding gas is exposed to a lesser converging heat of radiation and is not subject to thermal decomposition or cracking. The central air supply, being thusly preheated, gives a condition favorable to the formation of

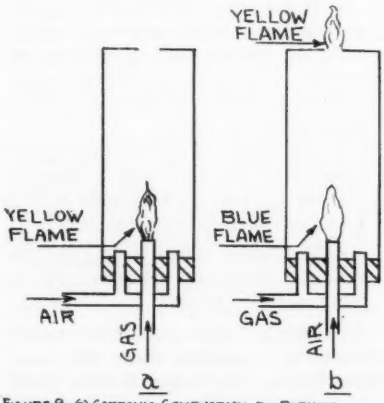

FIGURE 8. (a) CARBONIC COMBUSTION BY BURNING GAS IN AN AIR ATMOSPHERE. (b) ALDEHYDEOUS COMBUSTION BY BURNING AIR IN A GAS ATOMSPHERE.

peroxides, a first step in the resulting aldehydeous or blue flame combustion process. Thus, it is possible to obtain both types of combustion with the same gas, simply by altering the burner design.

The Bunsen burner, Figure 9a, is an example of a burner designed for aldehydeous combustion in order to allow the flame to come in contact with vessels without forming soot. The burner design accomplishes this by admitting the gas through a small jet at the base of a long mixing tube. Air is also admitted at the base of the tube by side openings, which permit a pre-mix of gas and air prior to the combustion zone. It also lessens the rapidity with which the hydrocarbons become heated (as compared to the case of Figure 9b, where no air pre-mix takes place) and this gives the oxygen time to penetrate the hydrocarbon molecules to form unstable hydroxylated compounds which burn with a blue flame.

The other combustion extreme, carbonic, also can be designed for by eliminating the air-gas pre-mix and relatively slow preheat. Thus, if the air ports of the Bunsen burner are closed, the gas reaches the combustion zone without an air pre-mix, Figure 9b. Here the rich gas is immediately subject to high temperatures where it undergoes thermal decomposition, and is finally broken down into hydrogen and carbon. The hydrogen readily burns, and the free carbon glows to incandescence to make a yellow and highly illuminating flame. This combustion type is the basis of burners designed for illuminating purposes, such as the common fishtail burner of the gas light era.

Actually, both general types of combustion occur in the flames of industrial oil burners, and it is well to recognize the conditions favorable to these two combustion extremes so as to take full advantage of them. The conditions

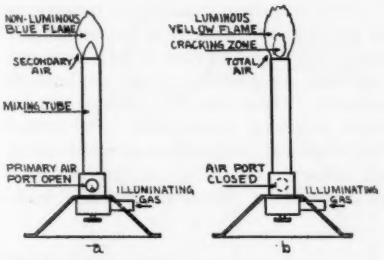

FIGURE 9. (a) ALDEHYDEOUS COMBUSTION WITH A BUNSEN BURNER. (b) CARBONIC COMBUSTION WITH A BUNSEN BURNER.

favorable to the blue flame or aldehydeous combustion process, are:

a. Complete fuel atomization and thorough mixing with air prior to combustion.

b. Preheat of the air supply to promote the formation of peroxides.

c. Protection of the mixture from high radiant heat to forestall "cracking."

Some domestic oil burners meet all of these conditions and obtain a predominately blue flame combustion, which is soot-free. The high burning rate, however, required of industrial burners prohibits practical establishment of all of these conditions. Consequently, the flame of most oil burners follows predominately a carbonic process. The conditions favorable to the production of this yellow flame or carbonic combustion process are:

a. Poor fuel atomization.

b. No pre-mix of the fuel and the air prior to combustion.

c. No pre-heat of the combustion air.

d. Poor air-oil mixing, resulting in oil or oil gas cracking without oxygen available to complete combustion.

e. Sudden exposure of the fuel to high radiation causing "cracking."

Soot formation under these conditions is possible, particularly if the associated air register and furnace design does not facilitate completion of the combustion process. These are the external conditions affecting combustion. The actual fuel chemical composition also will exert an influence on the predominating type of combustion. However, fuel oil blending, changes in supply sources, and the increasing poorer "burning quality" of available fuel oils, leaves little choice but to design for the worst.

Each basic type of combustion has its advantages and disadvantages for industrial oil burning and many of these follow:

BLUE FLAME COMBUSTION

Advantages:

Sootless operation under all combustion conditions. This insures high heat transfer across boiler tubes due to clean external surfaces.

Disadvantages:

a. Low combustion rate. This restricts burner capacity.

b. Long flame travel. This requires large furnaces if flame impingement is to be avoided.

c. Low heat transfer by radiation of the flame. This reduces the extent to which radiant heat absorbing surface can be used in the boiler furnace, thereby requiring more heat absorbing surface in a larger boiler tube bank for the same overall heat transfer.

YELLOW FLAME COMBUSTION

Advantages:

a. High rate of combustion with a short flame. This results in small, short furnaces.

b. High heat transfer by radiation of the flame. This permits the use of furnace water cooling surface with subsequent high heat release rates and accompanying reduction in furnace and boiler tube bank size.

Disadvantages:

a. Forms soot under poor combustion conditions. This is not only objectionable from the combustion efficiency standpoint, but the soot deposits on the boiler tubes reduces heat transfer, and provides fire and explosion hazard within the boiler and breeching.

b. Requires special furnace design consideration in the region of the short hot flame to prevent damage to the brickwork.

Since neither of these combustion extremes prevail alone in industrial oil burners, it is the designer's problem to develop a compromise burner design that will provide for as many of the most favorable features of each type of combustion extreme. For instance, oil atomization can be accomplished by dynamic pulverization through velocity imparted to the oil by the oil supply pressure by mechanical means, such as rotary disks, or by foreign aids, such as steam or air. Air-oil mixing is aided by air registers, and often preheated air is supplied. Each of these is, of course, directed toward blue-flame combustion.

Toward the end of yellow flame combustion is:

a. The absence of air-oil pre-mix prior to subjecting the combustible to the furnace.

b. Incomplete air-oil mixing, particularly at the center of the oil spray where air penetration is difficult.

c. Sudden exposure of the fuel to high furnace radiation.

d. Absence of preheated air.

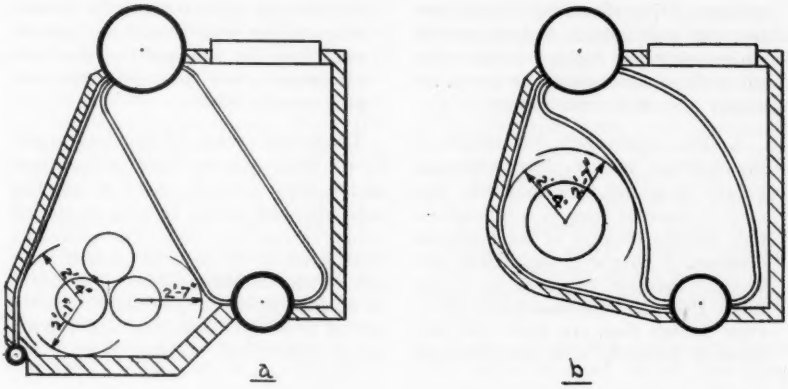

FIGURE 10. TYPICAL MINIMUM BURNER CLEARANCES FOR RESIDUAL FUEL OIL.

Although the results of most combustion processes for the generation of heat are hybrid flames in which both aldehydeous and carbonic combustion types occur simultaneously with a host of intermediate reactions, the flames of industrial oil burners are predominately of the carbonic, or yellow flame, type. There is nothing wrong with burners in which this type combustion predominates; in fact, it makes possible high burning rates and small size, high radiant heat absorbing water-cooled furnaces.

Two prime factors in completing combustion are the relation of the atomizer to furnace and boiler tube surfaces, and the degree of oil atomization and air-oil mixing accomplished by the atomizer.

The first of these factors largely establishes the furnace size. It requires that experimentally determined minimum clearances (less than which will disturb the combustion and form soot or carbon deposits on the interfering surface) be maintained, thus the limits of the combustion zone under the most adverse firing conditions set the furnace size. Figure 10a illustrates this method of establishing many of the furnace dimensions of a typical multi-burner boiler by employing a typical set of "clearance" dimensions for several types of furnace surfaces. Figure 10b also illustrates the use of clearance dimensions for a single high capacity burner to obtain a furnace of minimum size and weight. While larger air registers and drafts are required for such a high capacity burner, it has not been found necessary to increase clearance dimensions when the fuel supply pressure remains constant.

These clearances will vary with:

1. The burning quality of the oil. For instance, light distal oils can be burned with smaller clearances than heavy residual Bunker C oil.

2. The oxygen content of the combustion supporting media. For instance, the clearances are less for

pressure firing where the oxygen content per unit volume is increased by maintaining the furnace under pressures above atmospheric, or for an air supply enriched with oxygen.

3. The temperature and nature of the clearance surface. For instance, a greater clearance to a cold tube surface is required than to a hot refractory surface because of the favorable combustion nature of the hotter surface. A greater clearance to screen tubes than to side waterwall tubes, even though they are both cold surfaces, is generally used to compensate for the gas flow toward the screen. Also, target wall clearances greater than those for side walls of the same construction are used to reduce impact erosion effects.

The second factor, oil atomization and air-oil mixing, is particularly important at the flame front in order to promote not only aldehydeous burning of the oil spray surface particles, but especially final burning of the free carbon as it comes from the flame center. One means of accomplishing or assisting this is the use of a foreign atomizing and mixing agent, such as high pressure steam or air.

FLAME ROAR AND FURNACE PULSATIONS

The position of the flame front, or separation between the burning and nonburning part of the fuel flow, is established by the equilibrium of velocity of flow and speed of combustion. This flame front is in continuous motion as the combustion process varies or hesitates between the aldehydeous and the carbonic with its higher combustion rate. That is, under predominately carbonic combustion conditions, the flame front lies closer to the burner tip than with conditions which are favorable to the slower aldehydeous type combustion.

These changes in prevailing predominating combustion conditions may be brought about by local variations in atomization, preheat, or air-fuel mixing. For instance, under a condition favorable to rapid carbonic combustion, such as high oil preheat from furnace radiation, the flame will move toward the source of fuel; that is, the atomizer tip and center of flame cone. However, as the tip is approached, the conditions become less favorable for sustaining carbonic combustion, due to a decrease in the preheat and decrease in the amount of available atomized and air-mixed fuel, with the result that the flame is blown back by the flow of the combustible to a position where a predominately aldehydeous or less rapid combustion type is established. This process is repeated as local variations in atomization, preheat, and mixing produces a combustion type alternating between the aldehydeous and carbonic extremes, and the effect is a vibrating flame front. When the flame is steady, the frequency of vibration is high, the amplitude low, and the noise level is not objectionable. As the flame front becomes less steady, its frequency decreases, amplitude increases, and a roar of objectionable noise level may result. As the frequency becomes extremely low, resonance with the oil burner front plate and boiler casing, which is usually large and of a low natural vibration period, may take place and can reach damaging proportions. Usually the latter pulsation condition is associated with low rate operation when conditions favorable to one of the two extreme combustion types are less clearly defined. Often pulsations can be eliminated by a slight change in any of the combustion influencing factors, such as changing the oil spray angle, adjusting the air register, or raising the draft.

When the origin of furnace pulsations is from fluctuations in the fuel supply, such as might result from a reciprocating fuel service pump, or from exces-

sive fuel preheat causing vapor bubbles in the line, adjustments of the nature mentioned above are of little avail. However, these conditions do not cause serious or objectionable burner front and furnace pulsations, since they result in a high frequency, as in the case of a reciprocating fuel service pump, or of non-periodic frequency, as in the case of vaporization in the fuel supply line.

Pulsation or roar phenomena occur with both straight pressure atomizers and steam atomizers. Steam atomizers are generally far less troublesome, primarily because they are designed to insure the predominance of a constant set of combustion conditions at all fuel rates, and secondly, the steam, in addition to performing the primary atomizing and mixing requisite, also acts as a stabilizer.

An intense roar, however, may result with external mix atomizers of a kind shown in Figure 14, when the steam cone or jets cut too deeply into the flame center. The effect of cutting acutely into the flame center, where cracking and the first stages of carbonic combustion are taking place, is a local disturbance of normal processes and the creation of unsteadiness. Occasionally, high pressure air, instead of steam, has been used to assist atomization or air-fuel mixing. The additional oxygen thus supplied aids combustion as well as assists atomization and mixing without a fresh water loss, since the steam used to drive the air compressors could be condensed. However, if these air jets cut acutely into the flame, they will produce a violent flame roar, since each individual jet tends to set up an aldehydeous combustion type zone well within the primary stage of a carbonic combustion type zone, with the result that a very unsteady flame front prevails. In general, the use of high pressure air has several drawbacks, such as:

1. The expanding air, unlike steam, produces a much greater cooling effect on the oil spray, with a corresponding unfavorable combustion effect.

2. Its unit volume, expanding from the same pressure, is far less than steam; hence, its mixing ability is also less.

3. The amount of air supplied in this manner is only a relatively small percentage of the total required combustion air; therefore, its merit as an oxygen supplier is nil, and natural draft or blowers must still be relied upon to supply the combustion air. However, many domestic oil burners use light fuel oil and employ atomization and pre-mixing by low pressure air of the total quantity required for combustion.

4. The compressor required is another piece of heavy, bulky equipment that must be maintained.

It is emphasized that the two combustion type extremes indicate trends, rather than the existing actual state of combustion, since each, as well as a host of intermediate types, exist simultaneously.

STEAM ATOMIZING OIL BURNER CLASSIFICATION

Oil burners using steam for atomization may be grouped into three general categories—external-mix, internal-mix, and hybrid-mix, depending upon whether the steam contacts the oil outside the atomizer, inside the atomizer, or both outside and inside the atomizer. It also is possible to differentiate between each of these three classes:

1. External-mix:
   - A. Drooling
   - B. Shearing
   - C. Wiping
2. Internal-mix:
   - A. Simple mixing chamber
   - B. Injection chamber
   - C. Rotary chamber

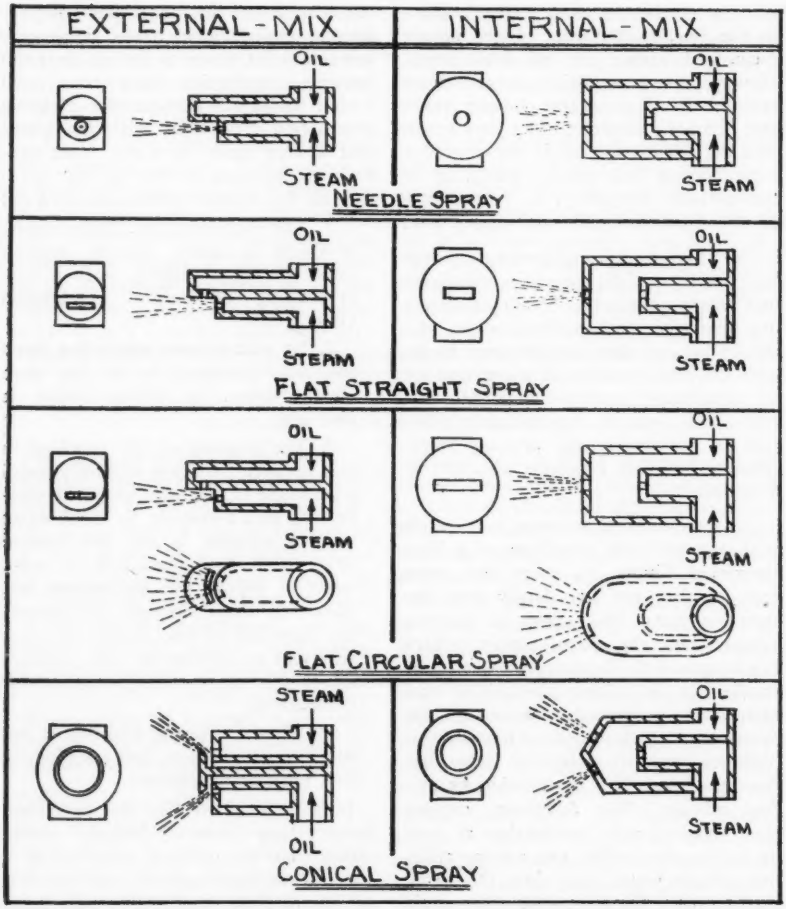

FIGURE 11 SCHEMATIC ARRANGEMENT OF EXTERNAL-MIX AND INTERNAL-MIX ATOMIZERS FOR VARIOUS SPAY SHAPES

3. Hybrid-mix:

A. Shear-chamber
B. Jet-chamber

Further, it may be possible to group each of these types according to shape of outlet orifice or the oil spray shape produced; for instance,

a. Circular orifice — needle-like spray
b. Flat straight orifice — narrow flat spray
c. Flat circular orifice—fan shape spray
d. Annulus orifice—hollow cylindrical or cone-shaped spray.

The spray shape for all steam atomizers can be made to conform to any one of these four spray shapes by altering construction details. This is a most advantageous factor which can be used in adapting atomizers to various installation requirements. This procedure is illustrated in Figure 11, which shows a schematic arrangement for obtaining the full range of sprays for simple external-mix and internal-mix atomizers.

EXTERNAL-MIX ATOMIZERS

External-mix atomizers are the oldest of the three basic types of steam atomizers. In general, they have the highest steam consumption, due primarily to their inherent design, which fails to bring all the steam properly to bear upon the oil. Atomization is accomplished by virtue of steam and oil impact, and spray distribution by the orientation and shape of the outlet orifices and the volumetric expansion of the steam-oil mixture. The capacity is not sensitive to variations in steam pressure or moisture, as is the internal-mix type, since the steam exerts no back-pressure upon the oil.

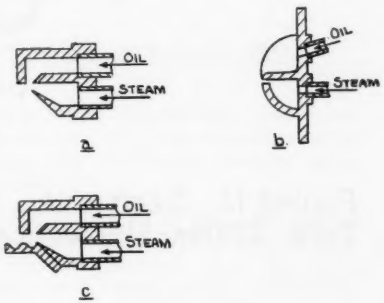

FIGURE 12. SCHEMATIC ARRANGEMENT OF EXTERNAL-MIX ATOMIZERS

Forms of external-mix atomizers are shown schematically in Figure 12. They all consist of two adjacent orifices. Oil is fed through one, while the other supplies the steam for atomization. When the oil is fed by gravity and drips directly in front of the steam orifice, Figure 12a, or drips on a trough, Figure 12b, the atomizer is often called a "drooling" type. When the oil is supplied under pressure and is struck by a jet of steam, usually at right angles or close thereto, just as it emerges from the orifice, the atomizer is often called a "shear" type. The essential difference between the so-called "drooling" and "shear" types is the magnitude of the supply oil pressure. Various modifications can be made by employing splash plates, Figure 12c, or similar devices.

The fuel should be preheated to facilitate fluid flow in the fuel oil piping system and small atomizer passages, and to improve combustion. Preheating is accomplished in conventional type fuel oil heaters, and in many designs often is supplemented at the burner by the steam tube surrounding the atomizer barrel, Figure 13.

Atomizing steam consumption of these types of external-mix atomizers is high, and to reduce steam consumption and to obtain a more suitable spray distribution, modern designs have taken advantage of the favorable characteristics of straight mechanical pressure atomization, and incorporated these in external-mix steam atomizers to obtain a combination steam and mechanical pressure atomizer having good atomization and spray distribution over a wide capacity range.

The external-mix steam atomizer shown in Figure 13 uses a combination of atomization by straight mechanical means, oil pressure, and auxiliary surface atomization (a surrounding enve-

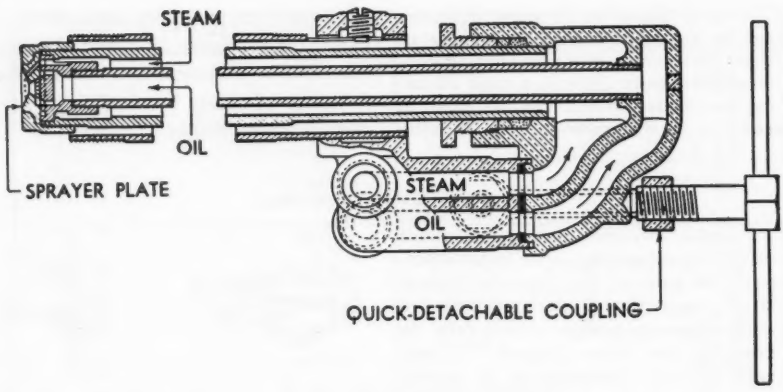

FIGURE 13. SECTIONAL VIEW OF EXTERNAL-MIX TYPE STEAM-MECHANICAL OIL ATOMIZER.

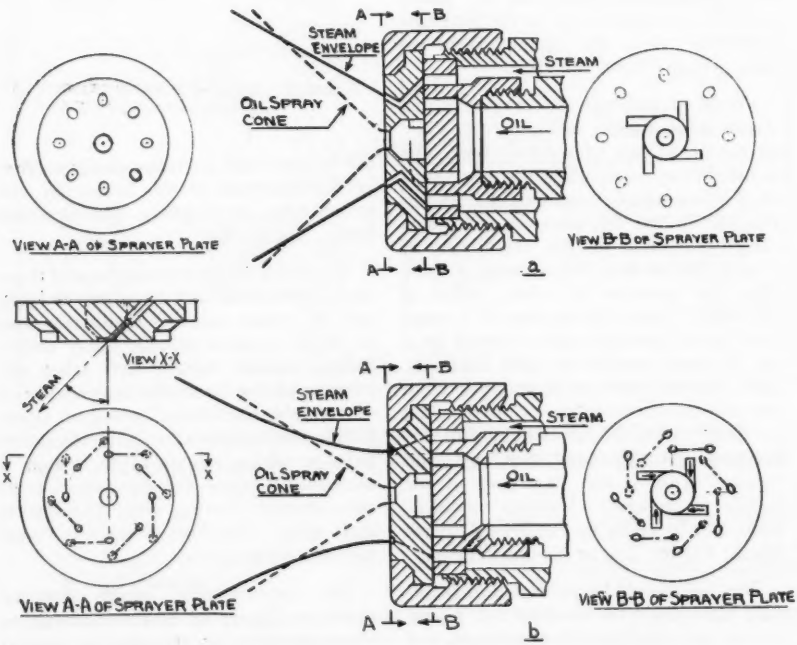

FIGURE 14 SPRAYER PLATES FOR STEAM MECHANICAL OIL ATOMIZERS

lope of high velocity steam) to obtain a wide capacity range atomizer. It is properly designated a steam-mechanical atomizer. The atomizer consists of a double barrel in which steam passes through the outer annulus passage, and oil through the central tube, to a common sprayer plate. The oil enters a whirling chamber in the sprayer plate through tangential slots, which give it a whirling motion as it passes to the outlet orifice. The oil emerges from the outlet orifice in the sprayer plate as a hollow conical atomized spray. The steam passes through a series of small circular holes located around the oil outlet orifice in the sprayer plate, and is directed so that the enveloping steam cones will wipe the oil spray cone.

Two methods of arranging the steam holes to obtain the desired cone effect are shown in Figure 14. The method shown in Figure 14a orients the steam orifices as the elements of a cone. In the second scheme, shown in Figure 14b, each of the steam orifices is located in a plane tangent to a common pitch circle, and at an angle to a perpendicular to the pitch circle equal to one-half the desired steam cone apex angle, α'. This results in a hyperboloid form of enveloping surface. Its profile can be constructed by plotting the intersection of the axis of these steam orifices with a central axial plane, as shown in Figure 15.

All contact between the steam and the oil occurs external of the sprayer plate; hence, atomizers of this type are, as previously stated, not sensitive to variations in steam quantity. Atomizers of this type may be operated as straight mechanical pressure atomizers, provided the minimum oil pressure is approximately 75 p.s.i. With unfavorable furnace conditions or with inferior burning fuels, steam can be introduced through the same sprayer plate to assist atomization. This method of operation increases the capacity range of the burner appreciably by making it possible to reduce

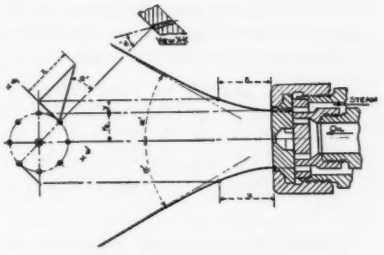

FIGURE 15. GRAPHICAL CONSTRUCTION OF STEAM ENVELOPE PROFILE FOR AN EXTERNAL-MIX STEAM MECHANICAL ATOMIZER

firing rates considerably below the satisfactory minimum obtainable when using only mechanical pressure atomization.

The orientation of the steam and oil spray cones is important, since the best results are obtained when the steam wipes the oil spray surface. This causes surface atomization, air combustible mixing by sort of a "peeling action," and provides a catalytic agent to promote oxidation of free carbon as it passes through the flame front. If the steam is directed highly convergent with the oil spray, it does not fully serve its purpose since:

a. There is insufficient steam for atomizing the total amount of oil.

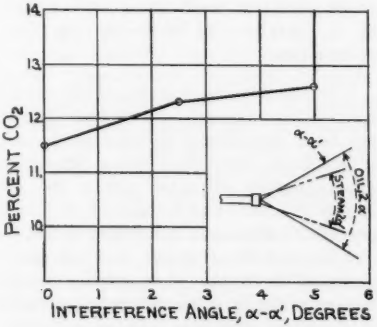

FIGURE 16. EFFECT OF STEAM AND OIL INTERFERENCE ANGLE ON COMBUSTION FOR A STEAM-MECHANICAL ATOMIZER.

b. It disturbs the first stages of the predominately carbonic combustion occurring at the flame center.

c. The benefit of air-combustible mixing by the peeling action is lost. When the steam is directed highly divergent to the flame front it, of course, loses its atomizing effectiveness.

Figure 16 shows the effect of the steam and oil interference angle on combustion as measured by stack CO_2 readings at trace smoke. Here the steam angle was taken as the exit angle of the steam orifice, and the oil spray angle measured under still air conditions. For simplicity of illustration, the still air spray angle has been taken as the flame angle, and effect of air register design, combustion air velocity, combustion process, etc., has been neglected; however, since establishing a trend is the purpose, choice of base is immaterial. It is seen that orientation of steam and oil cones does influence combustion, and that a steam cone that heavily wipes the oil cone gives superior results to one which is essentially parallel. The important thing is not to interfere with the normal combustion process in the central region of the flame, but to atomize the surface particles and assist in mixing the combustible with air for rapid complete combustion while acting as a catalyst to promote soot-free combustion.

The amount and velocity of the steam required to properly assist atomization has been determined by experience, and it has been found that steam pressures approximately 20 p.s.i. above the oil supply pressure and in amount of 1 to 5 percent of the steam generated is ample. While control of steam and oil pressures is desirable to minimize steam consumption, it is by no means critical in the sense that it is with many atomizers of the internal-mix type, where unbalances can stop the flow of either the steam or oil.

The capacity range of steam-mechanical type atomizer is 4-8 to 1, depending upon the maximum available oil supply pressure and size of sprayer plate—the greater range being associated with high oil supply pressures and high capacity sprayer plates.

Performance of a typical steam-mechanical atomizer, operating under both no-control and automatic steam control conditions is shown in Figure 17. The oil rate varies substantially as the square root of the supply pressure (similar to straight mechanical pressure atomizers). The simplest method of operation consists of supplying a constant amount of steam at all times, irrespective of oil rate. The amount of steam supplied would be that required for atomization at the most unfavorable rate, and while this is the simplest, in that no steam regulating controls are required, it is also the most costly from a steam consumption standpoint. The steam consumption for this type of operation is shown by the dotted curve of Figure 17 to vary from a maximum $62/90 = .69$ lb. of steam per lb. of oil at the minimum capacity to $62/500 = .12$ lb. of steam per lb. of oil at maximum capacity. In terms of total boiler steam output, steam consumption ranges from approximately 5 percent at the minimum to 1 percent at the maximum

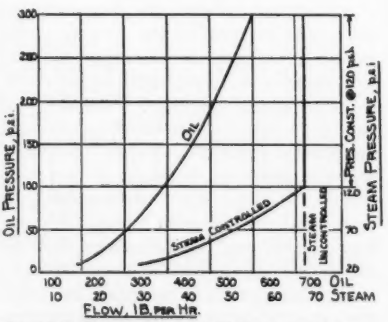

FIGURE 17 TYPICAL FLOW CHARACTERISTICS OF A STEAM-MECHANICAL ATOMIZER.

capacity, and is prohibitive when operating a good portion of the time at minimum capacities.

More efficient operation is obtained by automatically controlling the steam so as to vary its consumption with the oil rate. This is shown by the full curve of Figure 17, where the steam pressure has been held a constant amount (20 p.s.i.) above the oil pressure until an oil pressure of 100 p.s.i. is reached, at which point no further increase in steam pressure is required, since satisfactory atomization is obtained by oil pressure alone. Steam is held constant at 120 p.s.i. as oil pressure is further increased to obtain higher capacities mainly to prevent the steam orifices from becoming clogged or carbonized with combustible matter. It also simultaneously performs atomizing, mixing, and catalytic functions. Oil supply pressure as low as 10 p.s.i. will establish a partially atomized spray cone which the steam can supplementally atomize to a satisfactory degree. At this minimum oil rate, Figure 17 shows the atomizing steam requirement to be $27/90 = .3$ lb. of steam per lb. of oil. The steam consumption improves with capacity, reaching a value of $62/500 = .12$ lb. of steam per lb. of oil at the maximum rate. In terms of boiler steam output this ranges from 3 percent at the minimum to 1 percent at the maximum oil rate.

While the steam consumption of the steam-mechanical type atomizer may be prohibitive for ocean vessels, it is less critical for dredges, tugs and river and lake boats, where fresh water stores are more readily available. Application of this type of external-mix steam atomizer for such installations, where the frequent variable nature of the load requires the flexibility afforded by steam atomization, has been widespread and successful.

INTERNAL-MIX TYPE ATOMIZERS

Internal-mix atomizers incorporate a chamber into which oil and steam are introduced prior to discharge into the furnace. Atomization of the oil is accomplished by first mixing the oil and steam by jets, venturi tubes, etc., to form an oil-steam emulsion, and then discharging this emulsion, by the prevailing chamber pressure and velocity head, into the furnace. The oil-steam emulsion formed in the chamber is under a pressure well above that in the furnace, and upon discharge, its free expansion, together with the orientation and shape of the outlet orifice, provides for the dispersal of the oil particles. As shown schematically in Figure 11, the shape and orientation of the discharge orifice can be used to establish, to a great extent, the spray distribution of a simple internal-mix atomizer.

Due to the back pressure effect of the steam on the oil supply to the mixing chamber, atomizers of this type are more sensitive to variations in steam pressure than those of the external-mix type. They also result in high degree of oil preheat by direct steam contact, thereby requiring only oil preheaters of a size sufficient for liquid flow to the burners. Low fuel oil supply pressures are ordinarily used, since the pressure is required only to deliver the oil to the mixing chamber and not for atomization. These features facilitate large fuel oil passages—one of the main advantages of this general type of atomizer. Thus the burner can handle extremely low grade viscous fuels, such as heavy sludge, tar and industrial wastes.

A simple form of internal-mix type atomizer is shown schematically in Figure 18a, and consists of a single mixing chamber, into which steam and oil are fed by adjacent orifices, discharging into a single outlet orifice. Modifications to the mixing unit, such as the venturi of Figure 18b or the

multi-chamber of Figure 18c, have been used to improve mixing. Further, various methods of introducing the steam and oil, such as the combination of axial and tangential steam orifices for the preliminary churning of the oil prior to its entrance to the main mixing chamber, as shown in Figure 18d, or the opposed orientation of the steam and oil orifices shown in Figure 18c, have been employed in an effort to improve the mixing or emulsifying the oil prior to discharge into the furnace.

The oil-steam sprays issuing from the circular or slotted outlet orifices shown in Figures 18a, 18b and 18c are long and narrow, which limits the capacity of such atomizers, because of the difficulty of obtaining satisfactory air-oil contact along the entire length of the spray, especially when all of the combustion air is supplied as primary air at the air register. Consequently, atomizers were designed to operate with wide-angle conical-shape sprays. Some of these designs are shown in Figure 18d, and the various whirling chambers of Figure 19. Wide-angle, conical-shape sprays provide better air-oil contact conditions and are also more suitable for use in short furnaces.

Many designs imparting a whirling motion to the oil, steam, or both, have been used to improve atomization and shape of spray. A type which imparts rotary motion to both the oil and the steam is shown in Figure 19a. Here the mixing chamber is a relatively large venturi throat into which also is introduced high pressure combustion air. Undoubtedly, the introduction of the air in the mixing chamber promotes air-oil mixing. The requirement for supplying the total combustion at high pressure limits the practical and economical use of such types of atomizers to relatively small capacities. However, in special installations, or for short time operation under difficult burning conditions, high pressure air may offer the best solution.

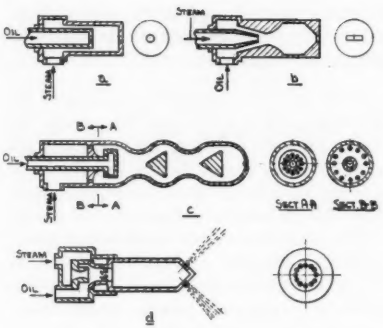

FIGURE 18 SCHEMATIC ARRANGEMENT OF INTERNAL-MIX ATOMIZERS

Occasionally, efforts are made to aspirate a large portion of the combustion air by placing such atomizers in the throat of the burner opening in the furnace wall, but again, the quantities of high pressure steam or air necessary to aspirate any appreciable portion of the combustion air are usually prohibitive.

Figures 19b and 19c show schematically atomizer constructions which give an initial whirling motion to only the oil. In Figure 19b the oil is given a rotary motion by arranging for its tangential entrance to the mixing chamber. The steam enters axially at the rear of the chamber and the final mixing with the oil takes place at the chamber exit by a shearing process.

In Figure 19c the oil is given an initial whirling motion by passing it over a screw thread prior to its entrance to the mixing and whirling chamber. The steam enters the chamber by an annulus surrounding the oil barrel, emulsifies the oil in the whirling chamber, and then discharges with the oil in a conical shape spray.

A high fuel oil supply pressure and preheat is required in order to obtain any appreciable degree of rotation when only the oil is given an initial whirling

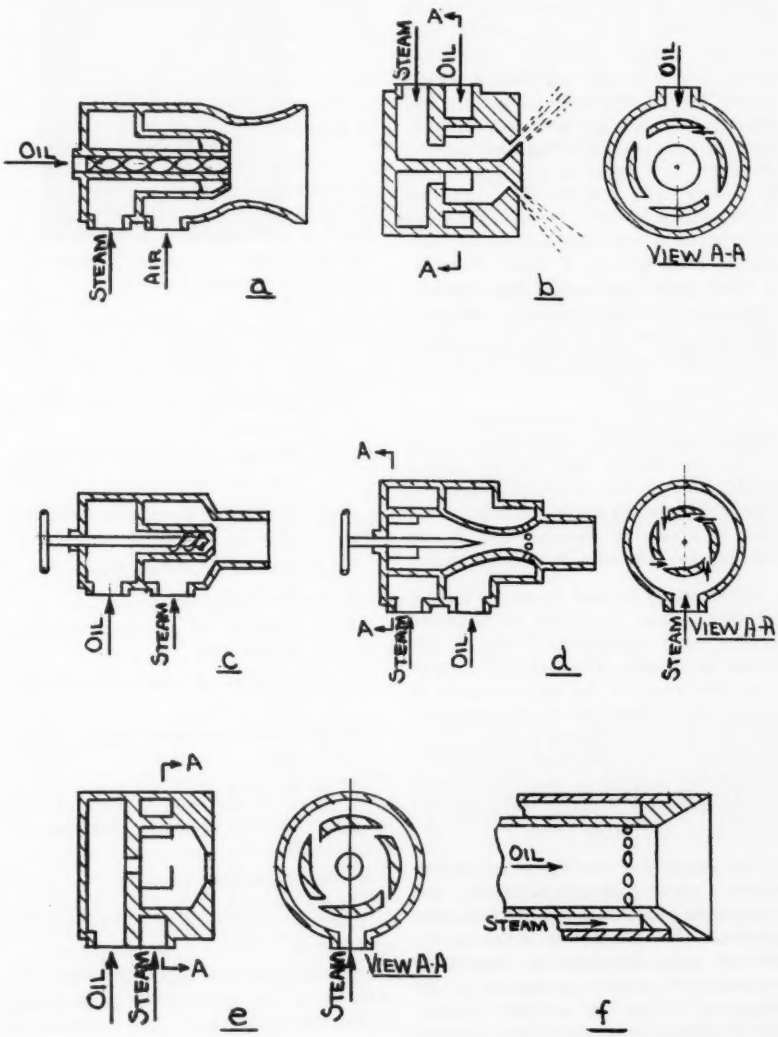

FIGURE 19, SCHEMATIC ARRANGEMENT OF INTERNAL-MIX WHIRLING CHAMBER TYPE ATOMIZERS

motion. This disadvantage is not encountered in the designs shown in Figures 19d, 19e and 19f, where high pressure steam, available from the boiler, is used as the initiating whirling agent. Hence, the fuel oil pressure and the degree of preheat need only be sufficient to provide flow to the mixing chamber. The design of this type shown in Figure 19d consists of a venturi throat through which steam, that has been given a whirling motion by tangential inlet slots to a steam chamber, is discharged into a mixing chamber. The oil enters the whirling chamber through a series of radial orifices located around the periphery of the mixing chamber.

In Figure 19e the steam enters tangential to a mixing chamber to set up a whirling motion and the oil enters axially at the rear of the chamber. In Figure 19f the oil enters axially at the rear of a mixing chamber and is set whirling by tangentially directed steam.

When steam is used as the initiating whirling agent, it should be admitted on the outer periphery of the oil, as shown in Figures 19e and 19f, instead of on the inside of the oil, as shown in Figure 19d. Thus, the steam must pass through the oil to impart its full whirling motion, direct preheat, and perform emulsifying actions as it flows toward the chamber axis, because of the induced centrifugal separating force.

The extent to which this separating action is avoided largely determines the combustion characteristics of this type atomizer. The separating action is dependent upon keeping the separating resistance to relative movement of the steam and oil as high as possible, and the centrifugal separating force as small as possible, consistent with a satisfactory spray angle and degree of mixing. The separation resistance of the oil and the steam emulsion is enhanced by keeping the fuel oil viscosity as high as possible at the entrance. Within the whirling chamber the oil viscosity decreases rapidly as the oil becomes heated by direct steam contact. The centrifugal separating force is determined by the ratio of the whirling chamber to outlet orifice radii, which should be as small as possible.

The magnitude of the centrifugal separating force action on the oil-steam emulsion depends upon the whirling chamber dimensions. For instance, the separating force per unit of volume of a mixture of two densities is:

$$f_c = \frac{V^2}{r} (\rho_2 - \rho_1) \qquad (6)$$

where:

f_c = Separating force per unit of volume, lb. per cu. ft.

r = Radius of any point in whirling chamber, ft.

r_i = Radius of tangential inlet orifice, ft.

r_o = Radius of outlet orifice, ft.

L = Ratio, r_i/r_o

V = Velocity of oil-steam mixture, ft. per sec.

V_i = Velocity at inlet orifice, ft. per sec.

V_o = Velocity at outlet orifice, ft. per sec.

ρ_2 = Density of oil, slugs per cu. ft.

ρ_1 = Density of steam, slugs per cu. ft.

f = Separating force, lb.

g = Gravitational acceleration, ft. per sec.^{2}

It is seen that the separating force increases as the square of the velocity and difference in densities. The condition of a free vortex is assumed to predominate within the whirling chamber, since energy is neither added nor subtracted, so that,

$$Vr = V_1 r_1 = V_2 r_2 = V_n r_n \qquad (7)$$

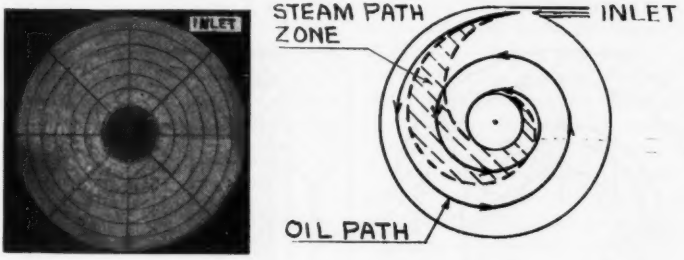

FIGURE 20. (a) PHOTOGRAPH SHOWING THE NATURE OF THE SEPARATION ACTION WITHIN A WHIRLING CHAMBER OF AN INTERNAL-MIX TYPE ATOMIZER. (b) TRACE OF THE FLOW PATHS AS DETERMINED FROM (a).

or the velocity of any point in terms of the inlet velocity, V_i, is:

$$V = \frac{r_i}{r} V_i \qquad (8)$$

and at the point of maximum velocity, outlet orifice,

$$V = \frac{r_i}{r_o} V_i = L V_i \qquad (9)$$

and substituting in equation (1) gives:

$$f_c = \frac{L^2 V_i^2}{r_o} (\rho_2 - \rho_1) = \frac{L^3 V_i^2}{r_i} (\rho_2 - \rho_1) \qquad (10)$$

from which it is seen that the separating force decreases rapidly with a decrease in the ratio of whirling chamber to outlet orifice radii L. Even when maintaining the value of L as low as possible, consistent with a satisfactory spray angle (L also influences the angle of spray [2]), it is possible to obtain velocities so great that separation is accomplished in a fraction of the time it would take under the gravitational separation force.

$$fg = g (\rho_2 - \rho_1) \qquad (11)$$

The manner in which this separation takes place is shown in Figure 20, which is a photograph of the whirling chamber looking toward the outlet orifice of a model of an atomizer of the type shown in Figure 21.

The oil and steam action has been simulated by the use of water and air respectively. Flow path traces were observed by means of silk threads attached to the chamber face. Only one inlet was used in the model; however, actual atomizers employ a multitude of inlets so as to preclude the chance of an unbalanced spray. It is seen that the air separates from the water in but a fraction of a revolution; whereas, the water takes several revolutions from inlet to outlet. Within the whirling chamber vortex the pressure diminishes hyperbolically and the tangential velocity increases hyperbolically as the center is approached, Equation 8; hence, separation becomes more rapid both by virtue of the increased velocity and increase in the density differential as the bubbles

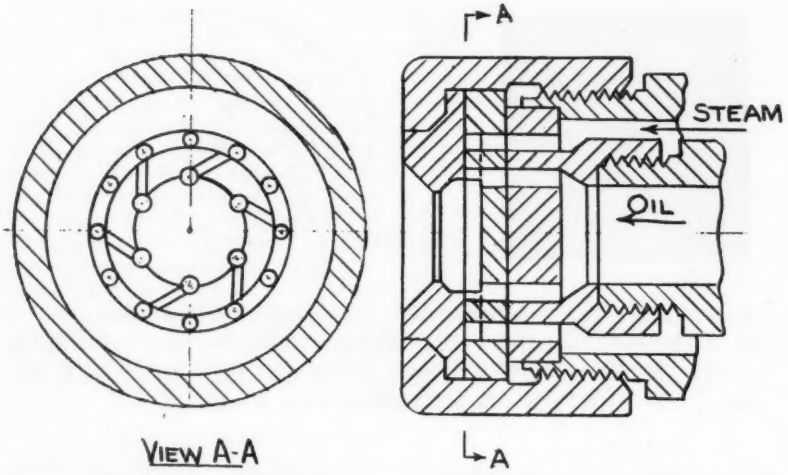

FIGURE 21. ARRANGEMENT OF WHIRLING CHAMBER INTERNAL-MIX TYPE ATOMIZER

expand under the lower pressure, Equation 10.

This sort of separation in steam atomizers is undesirable and results in a separate steam cone within the oil spray cone, with a corresponding loss of the atomizing and mixing energy of the steam. Though an inherent disadvantage, it can be minimized by:

(a) Limiting the oil preheat prior to entering the whirling chamber to an amount necessary for flow purposes only in order to initially provide a high viscous separation resistance.

(b) Restricting the size of the chamber to that minimum consistent with satisfactory direct oil preheat and emulsification in order to reduce the time available for separation.

(c) Using the smallest ratio of whirling chamber radius to outlet orifice radius necessary to obtain the desired spray angle [2]. This will keep tangential velocities, hence separation, to a minimum.

A good compromise of these factors to obtain a satisfactory combination whirling and mixing chamber is shown in the atomizer design of Figure 21. The fuel flow passages are kept large, which is of particular importance when using fuels carrying large particles of foreign matter. The large fuel flow passages, and the fact that oil pressure is not required for atomization purposes, facilitates the use of low oil pressures, sufficient only to deliver the fuel to the chamber. The steam is projected at right angles across the oil jets, and heats and emulsifies the oil as it is set rotating in the whirling chamber. The mixture is then discharged through a central outlet orifice in the form of a hollow cone-shaped spray. Atomization is accomplished both by the centrifugal force imparted to the oil as it leaves the outlet orifice, and by the free expansion

of the steam-oil emulsion from the chamber discharge pressure.

This type of atomizer has been successfully used for capacities up to 4500 pounds of oil per hour. The steam required for satisfactory atomization varies widely with the fuel quality, and will approximate 1 to 10 per cent of the boiler output.

The ability of atomizers of this type to effectively handle low grade fuels and wastes at comparatively low pressures and preheat temperatures has led to its adoption in many industrial installations. It has not been used in marine service, because the fuels commonly used have not deteriorated to the point where this type of atomizer is mandatory. Should such deterioration develop, or should the use of "suspended" or "collodial" fuels, such as pulverized coal and oil, become general, this type of atomizer may find a place in marine service.

HYBRID ATOMIZERS

Efforts to incorporate desirable features of both the internal-mix and external-mix atomizer types into a single atomizer have led to several hybrid forms as shown in Figure 22. Figure 22a shows a combination type in which initial emulsification is done in an internal chamber, and, upon exit from this chamber the emulsion is further subjected to the action of an external steam jet. While the quality of atomization is good, the steam consumption is high. Figure 22b shows an atomizer that may be classed as a "shear-chamber" type. It has a series of small uniform diameter orifices oriented as the elements of a cone and connected to a central oil supply. Steam from a common source is introduced by a corresponding series of obliquely intersecting orifices. The steam atomizes the oil by shearing off successive layers as it is directed across the oil paths and deflected through the discharge orifices.

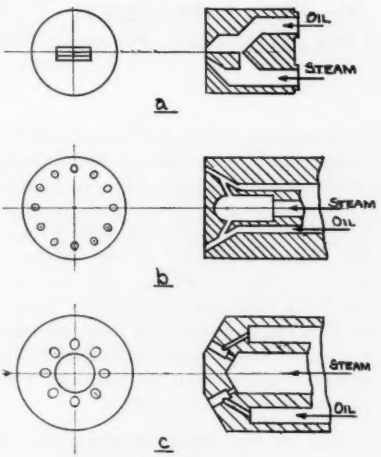

FIGURE 22. SCHEMATIC ARRANGEMENT OF HYBRID TYPE STEAM ATOMIZERS. (a) COMBINATION INTERNAL AND EXTERNAL MIX, (b) SHEAR CHAMBER TYPE, (c) JET CHAMBER TYPE.

When this design is altered by providing a small chamber at the junction of each steam and oil passage, the atomizer is called a "jet-chamber" type. Figure 22c shows diagrammatically the oil and steam flows in such an atomizer sprayer head of this type. The steam enters the central tube and flows through a multitude of small orifices located around the chamber. Each of these orifices enters a sudden enlargement forming a chamber in which the oil is introduced obliquely. Although the primary atomizing action is still one of shearing, the chamber provides a reduced velocity section and facilitates limited additional oil preheating and emulsification prior to discharge. Under

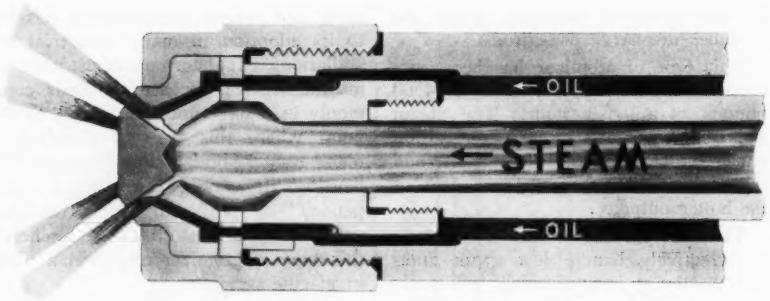

FIGURE 23 DIAGRAM OF OIL AND STEAM FLOW IN ATOMIZER AND SPRAYER PLATE OF Y-JET CHAMBER TYPE, WITH A RESISTOR IN THE OIL FLOW PATH.

the chamber velocity and pressure head, atomized oil, in the form of an oil-steam emulsion, is projected into the furnace to form a cone of jets. Each jet generally becomes a part of a solid cone as the steam, entrained in the oil-steam emulsion, freely expands. This arrangement of a multitude of small jets, located to form the elements of a cone, presents a greater and a more favorable air-oil contact surface than is obtained with single large size cone sprays.

One of the latest developments in steam atomizers of this type has been the Y-Jet Atomizer of Figure 23, so-called because of the shape of the oil and steam junction. It has shown excellent promise, particularly for ocean vessels, since good atomization is obtained at all rates with a maximum steam consumption of ½ to 1 percent, with an average of 0.7 percent at full load, of the boiler output. Its ability to provide smokeless combustion under all furnace conditions, coupled with its low steam consumption, led to its adoption on many World War II transports, and its installation on many postwar modern high speed tankers and passenger ships.

This type of atomizer generally operates with low pressure oil and steam, and good results are obtained with oil pressures of less than 100 p.s.i. This is because the oil pressure is not required for atomization, but only to deliver oil in the desired quantity to the atomizing chamber. Capacity would ordinarily be expected to vary approximately as the square root of the pressure, but the effect of the steam back pressure is to make this variation more nearly a linear one. With steady oil supply pressures, it can be operated with oil pressures as low as 2 p.s.i., but to prevent loss of ignition due to possible pressure fluctuations, oil pressures below 10 p.s.i. are seldom used. Low oil pressures can be retained in the jet chamber by placing resistors ahead of the sprayer plate, Figure 23. These resistors consist of a filler plate having one or two circular orifices. Although serving primarily as a pressure reducer, they also provide greater operating pressure differentials, thus facilitating the adoption of automatic controls.

A proper balance between the several orifices and chamber sizes is essential in order to obtain the maximum quality of atomization with the minimum steam consumption at all operating rates. Generally, the ratios of the steam, oil and jet chamber areas, which have been found to provide this desired balance, are maintained constant for all capacity sizes. As capacity increases, the size of the jet chamber is first increased, and then the number of chambers is increased. Capacities from 75 lb. per hr. for a single jet to 9000 lb. per hr. for a six-jet atomizer have been used. The optimum number of jets and the apex angle formed is established largely from experience, and the greater number of jets and larger apex angles are usually associated with higher capacities. The orientation of the jets should not permit the oil sprays to overlap and cause reconsolidation of the oil droplets or restrict combustion air contact surface by precluding air from all sides of each jet. The importance of using the proper apex angle for the cone jets is shown in Figure 24. This figure indicates that for the same capacity sprayer, and with all other furnace conditions constant, the percentage of CO_2 for trace smoke was increased by enlarging the apex angle from 75° to 80°. Further, it is noted that no benefit was obtained in going beyond the optimum 80° angle to 85°.

With this type of atomizer, total atomization comes from the steam and it is necessary to supply adequate energy at all times without a wasteful excess. It has been found that if the steam pressure is carried about 20 p.s.i. above the oil pressure, the best combustion conditions are obtained. This is illustrated in Figure 25, which shows that increasing the steam-oil pressure differential above 20 p.s.i. produces no combustion improvement (all other factors constant) and only results in an energy and fresh water loss.

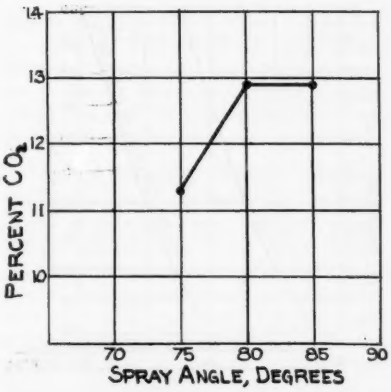

FIGURE 24. EFFECT OF SPRAY ANGLE ON COMBUSTION, JET CHAMBER TYPE ATOMIZER.

Since this type of atomizer is primarily of the shear principle, with the extremely small chamber affording but a secondary oil preheat, it is desirable to preheat the supply oil to the same degree as is required with straight mechanical pressure atomizers; that is, to a temperature which will give a viscosity of 135-150 SSU.

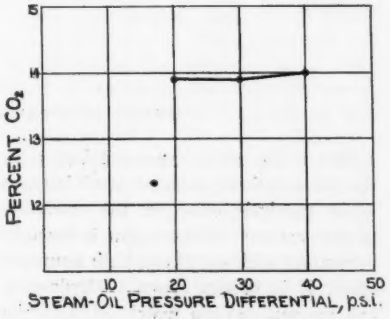

FIGURE 25. EFFECT OF STEAM PRESSURE ON ATOMIZATION AND COMBUSTION OF A Y-JET TYPE ATOMIZER.

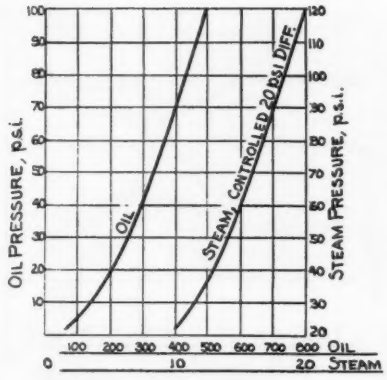

FIGURE 26. FLOW CHARACTERISTICS OF Y-JET TYPE STEAM ATOMIZER.

This atomizer may be operated in two ways. First, the steam pressure can be held constant corresponding to that at the maximum operating rate, and the burner capacity changed by varying the oil pressure only. While this may be well suited for manual or simplified control, it is much less economical than operating with the steam pressure approximately 20 p.s.i. above the oil pressure throughout the entire capacity range. With the latter procedure, it is usually preferable to employ automatic controls.

Characteristics of this type of operation are shown in Figure 26. The steam consumption varies from 10/70 = .14 lb. steam per lb. oil at minimum rate to 20/500 = .04 lb. steam per lb. oil at maximum rate, equivalent to 1 to ⅓ percent respectively of the steam generated.

The favorable atomizing steam consumption of the Y-Jet atomizer as compared to an external-mix type of steam mechanical atomizer, Figure 13, for the same capacity, is clearly indicated in Figure 27. While the Y-Jet offers no additional capacity range, its steam consumption is appreciably less.

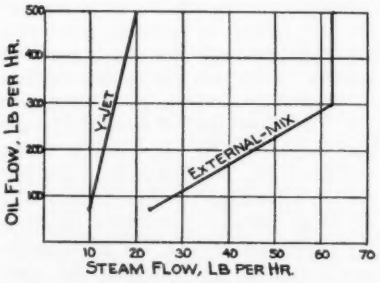

FIGURE 27. COMPARISON OF STEAM CONSUMPTION OF STEAM MECHANICAL EXTERNAL-MIX AND Y-JET TYPE STEAM ATOMIZERS

EFFECT OF STEAM ON SOOT PREVENTION

One of the most important factors in the successful use of steam in oil burners is its catalytic effect in the oxidation of free carbon. When steam is brought in contact with carbon at high temperatures, it is broken down to hydrogen, and nascent oxygen which oxidizes the carbon to carbon monoxide and carbon dioxide. This is known as the "water-gas reaction," and it was probably this, as much as any other particular design feature, that was responsible for the early successes with burning heavy fuel oils. It is the high affinity of nascent oxygen for the free carbon present during stages of the combustion process, that makes the amount of water present of prime importance as a soot-preventer. High temperatures also are necessary for this breakdown and reaction, Table

TABLE 1*

Temp. Degree F.	% H_2O Decomposed	% H Formed	% CO Formed	% CO_2 Formed
1250	8.8	65.2	4.9	29.8
1850	94.0	48.8	49.7	1.5
2050	99.4	50.9	48.5	.6

1*, which indicates that water introduced, or formed, at the beginning of the combustion process, where it will be available for maximum breakdown and reaction with free carbon, is more effective than that introduced, or formed, in the latter parts of the combustion process.

The water for such reaction comes not only from that introduced for oil atomization, but from the humidity of the air supply and from the combustion process itself. The purely chemical action of water vapor can be demonstrated by playing steam on a smoky oil lamp, or by introducing steam into a smoky furnace, such as to substantially eliminate any oil atomizing effects, and noting its smoke clearing effect. The use of steam jets within the furnace promotes mixing of the air and combustible, as well as dispersal of water vapor throughout the furnace. Steam atomizers, on the other hand, perform both oil atomizing and mixing in addition to water conditioning the furnace.

There are two prime losses accompanying the use of steam for this purpose. The first, and most important, is the loss of ½ to 5 percent of the steam generated when steam oil atomizers are used, which is both a drain on the boiler and evaporators. The second, and of less importance, is the heat loss due to the vaporization and superheating of the water added. While these are plant or boiler efficiency losses, they may not appear so appreciable when considered in light of the increased combustion efficiency, increased heat transfer due to a clearer furnace and cleaner tube bank, and less frequently required soot blower operation.

The increasingly poorer burning quality of available fuel oils, coupled with a marine boiler design trend toward highly rated small water-cooled furnaces, closed spaced tube banks, extended surface auxiliary heat reclaiming surfaces, wide range oil burners, and remote automatic combustion control, is giving impetus to the use of steam not only as an atomizing agent, but as a furnace water conditioner. When steam is not an atomization requisite, injection of water directly into the furnace, or introduction into the fuel oil line, has also shown promise. This will eliminate the item of steam demand on the boiler, but not loss of fresh water.

Another problem that the poorer grades of residual fuels has created, but which possibly may be controllable to some extent by steam atomization, is the slagging of high temperature superheaters. Crude oils contain sodium, calcium, magnesium, manganese, iron, nickel, and vanadium salts which are concentrated in residual fuels after the refining process. The increase in superheater temperatures, high firing rates, and closely spaced tubes employed on marine boilers, has created a set of conditions favorable to the accumulation of a hard slag containing these salts on the superheater tubes. The ideal solution of selecting fuels not susceptible to this slagging condition is seldom possible or practical, and the condition can only be expected to deteriorate as refining processes advance. Recently, on a tanker experiencing such difficulties when using straight mechanical pressure oil atomizers, a considerable reduction in slag accumulation over an equal period of

* Mellor's Modern Inorganic Chemistry, 1939, Pg. 365.

time resulted when steam atomizers of the Y-jet type, Figure 23, were substituted. Whether this was a direct result of an increase in the quality of atomization, the catalytic effect of the steam on the combustion process, or the catalytic effect on the slag forming process itself, is not definitely known, but the cure is an important one which is keynoting further steam atomizer installations.

THE PRESENT AND FUTURE OF STEAM ATOMIZATION

The position of steam atomization relative to straight mechanical pressure atomization has been enhanced in recent years by two major factors. First, a gradual decrease in the burning qualities and increase in high temperature superheater slagging qualities of heavy catalytically cracked fuel oils has taken place. Steam atomization has demonstrated its ability to satisfactorily cope with this problem. Secondly, the possible danger of damaging air heater and economizer soot fires resulting from mal-operation of straight mechanical pressure atomizers under adverse conditions, such as low port load, low fuel preheat and low fuel atomizing pressure, is largely eliminated by the excellent quality of steam atomization at all rates. These advantages are noteworthy, since closely spaced, and often extended, surface tubes act as traps for soot which can subsequently become ignited and cause damaging fires. Atomizing steam consumption is not exorbitant, ⅓ to 1 percent of the boiler output, and the advantages gained seem more than recompensable.

The future in marine boiler design is toward higher steam temperatures and pressures for economy, smaller closely spaced tubes for compactness, and wider capacity range oil burners for complete and possibly remote automatic operation. Such designs are highly susceptible to gas-side fouling; hence, the extent to which this end can be eliminated depends entirely upon the completeness of combustion at all rates. Steam atomization of heavy industrial fuel oil offers some promise toward this end, for not only does it give good atomization at all rates, but the water thus introduced apparently plays an important part in insuring soot-free combustion by vapor conditioning the furnace atmosphere.

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PRINCIPLES OF MISSILE GUIDANCE SYSTEMS

ACKNOWLEDGMENT

This article outlines the principles, problems and detailed developments in the field of missile guidance systems. It was published in the November 1951 issue of "Aero Digest."

Every major executive in the Department of Defense, be he civilian or military officer, has repeatedly stated publicly that missile guidance and control is the major stumbling block to the immediate achievement of push-button weapons.

Our purpose here is to explore the very widespread question: "What is there to the missile guidance problem that makes it so difficult?"

Investigation reveals that in few fields of technical endeavor is there so much lay misunderstanding. The simple word "missile" has been misinterpreted to mean the equivalent of "airplane" or "battleship" as simply another unit in this nation's arsenal. The truth of the matter is that this simple word actually represents not only a whole new array of weapons but an entirely new concept in warfare which will ultimately completely replace the airplane and the battleship if not armies themselves. It is not a difficulty with the electronic circuits for guiding a missile that is delaying progress, it is investigation and understanding of a whole new area in human thinking on warfare.

The major culprit in this public misunderstanding is official secrecy and the current security status of even the outermost fringe of this nation's guided missile program matches fully that of the wartime Manhattan Project. It is secrecy that inherently prevents understanding so that there can be no public sympathy for our guided missile program until World War III begins.

But principles are never military secrets; they are known to the Russian scientists as well as to our own, they are public property since time immemorial and always will be. Our purpose here, then, is to outline these principles and, by so doing, reflect something of the magnitude and complexity of the problem.

Since V-J Day, there has evolved in the Department of Defense the concept of the "weapons system" as distinct from pure weapons development. The Air Force, Army Ordnance Department and Navy Bureau of Ordnance, acting jointly through the Research and Development Board, are no longer concerned simply with the invention, development and production of new weapons *per se* but rather with the creation of weapons

TABLE 1

TYPES OF GUIDED MISSILES

AAM—Air-to-Air Missile (used by one aircraft in attack on another)

ASM—Air-to-Surface Missile (powered, guided aircraft bomb)

AUM—Air-to-Underwater Missile (powered, guided aircraft bomb used in Anti-Submarine Warfare)

SAM—Surface-to-Air Missile (anti-aircraft)

SSM—Surface-to-Surface Missile (artillery type, short-range types are tactical missiles, long-range types strategic missiles)

SUM—Surface-to-Underwater Missile (high-velocity, homing depth charge)

UAM—Underwater-to-Air Missile (anti-aircraft from submerged submarine)

USM—Underwater-to-Surface Missile (conventional torpedo)

A—Air; S—Surface; U—Underwater; M—Missile; A—Air Force; G—Army; N—Navy.

Example: SSM-A-3b, Surface-to-Surface Missile, Air Force, Third Model, Second Modification.

complexes in which a vast array of elements are teamed together to work as a unit. In the classic case of an attacking enemy A-bomber, the separate elements of early warning, intercepter dispatch, bomber tracking, interceptor vectoring, missile launching, anti-aircraft gun laying and firing and ultimate bomber destruction are integrated into a *single* weapons system all automatically controlled. That the early-warning radar may be located on a picket ship operated by the Navy, the interceptor belong to the Air Force and the anti-aircraft guns owned by the Army, is the essential necessity for an integrated armed forces: it created a single Department of Defense and is not a product of it.

Within these weapons systems lies a seemingly endless range of jobs for the missile and the foreseeable goal is the availability of a missile for *every* combat job, bar none. Thus the missile is being called upon to absorb the limitless array of combat articles previously requiring the services of the fighter and the bomber, the battleship and the submarine, the infantry soldier and the artillery. While the list of such jobs would require hundreds of pages, logical definition of the *types* of jobs to be done in battle has reduced this list to only eight functions, as shown in Table I. But within each of these functions lies a panoply of missiles ranging the gamut of human technical ingenuity in their type of propulsion, basic function, size, performance and general arrangement.

The process of evaluation alone taxes the human capacity and yet even these fantastic figures are multiplied into the hundreds of thousands when the more detailed aerodynamic and electronic problems of guidance are explored.

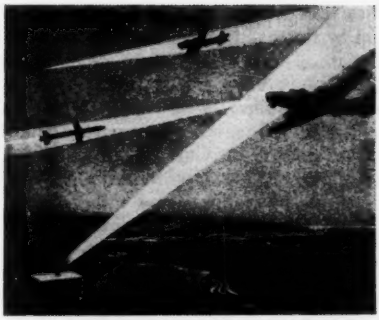
It is for this reason that the missile is far more a development problem than a basic research problem. As a consequence, great emphasis has been placed in the program on missile proving grounds and test programs, for the ultimate performance of a missile depends substantially on the extent to which all of its various elements have become compatible with each other, rather than how well each element performs unto itself.

If we assume that an enemy bomber is traveling at 600 mph. at 45,000 ft., in the 15 sec. required for the missile to reach that altitude, the bomber will have covered 13,200 ft., or 2½ miles. During that 15 sec. the bomber pilot will have to keep the bomber exactly on course with an accuracy of one part in 10,000—obviously extremely unlikely. If the bomber deviates from its course by only one-half degree, the conventional preset missile will miss it by 106 ft. It is clear that if interception is to occur, some method of re-directing the missile after launching is essential.

The simplest system of control is Command Guidance, in which signals from the ground are transmitted to the missile in flight. In this weapons system, the enemy bomber and the missile are continuously tracked by radar; changes in the bomber's course are detected and the variation in the missile flight path to a new line of intersection is automatically computed and radio signals are transmitted to the missile which move its controls to bring it to the new collision course. This may have to occur a number of times in the 15-sec. flight, reflecting the absolute necessity for very fast-acting equipment.

Next most complicated system is the Way-Following Guidance, or "Beam Rider" system. In this system, a radar beam is transmitted continuously at the bomber and equipment is contained in the missile which enables it to follow this beam to the target. This equipment not only detects when the missile is directly on the beam (which, itself, will be continuously moving with the bomber) but, also the direction and magnitude of its error when it is off the beam.

Further complicated is the Homing Guidance system in which the missile "homes" on the bomber. This system may take a variety of forms. In Active Homing systems, all of the necessary equipment is contained within the missile: i.e., it transmits a radar signal to the bomber, receives the reflected signal which is used to actuate the missile control system. In Passive Homing systems, the missile receives radiations emanating from the target. A further type is the Semi-Active Homing system in which the radar signal is sent from the ground (or a friendly airplane) and only the reflected signal is received in the missile, which adjusts its course thereby.



Two systems are shown: top shows missile illuminating and seeking target; below is method of ground illumination of target for seeking missile

With these three basic systems of guidance established, it is possible to examine each in detail to establish individual design requirements. The guidance system must work in complete harmony with the stability and control characteristics of the missile and these two characteristics are inseparable.

It was stated previously that the guidance system must be quick-acting. This is comparatively simple to attain. But after the required corrective signal has been obtained from the guidance system, it must be used to actuate a control surface and the missile deviate from its course. As is well known in piloted aircraft work, movement of a control surface immediately creates an oscillation in which the axis of the aircraft swings past the desired course in both

directions until the oscillation is damped out by the stability characteristics of the design. The rate and amplitude of these oscillations, while predictable in the design stage, varies with such minor considerations as manufacturing techniques, the center-of-gravity of the model (which is constantly shifting due to propellant burning), and even atmospheric conditions (temperature, pressure and density). Since tactical missiles will never be fired straight up, even sleek, wingless missiles will develop lift and their weight components will be inclined at progressively changing angles, both requiring corrective action from an automatic stabilizing system quite apart from the guidance system.

In conventional automatic stabilizing systems, use is made of *synchros,* a general term for such familiar synchronous devices as the Autosyn, Selsyn, motor torque generator, mag-slip and Siemens. These are single-phase, alternating current machines usually comprising a two-pole, single-phase rotor field and a Y-wound, single-phase, variable-voltage stator. The transmitting unit, whose rotor is actuated by some item of mechanical equipment, is called the generator and the receiving or "slave" unit, called the indicator, has a motor that is free to rotate and which is damped to prevent excessive oscillation before coming into correspondence with the rotor of the transmitter. Such synchro systems work only with the scalar quantity of the signal. When the signal must be amplified, the amount of the error measured and very rapid response is required, use must be made of a *servomechanism.*

The basic elements of a servomechanism (as distinguished from a synchro) include a feedback control system in which the difference between a reference input and some function of a controlled variable is used to supply an error signal to the control system. This error signal is amplified and is used to reduce to zero the difference between the reference input and the controlled variable. Since an exterior power source is used for amplification, such systems contain the possibility of self-excited oscillations or instability, and this is the heart of the servomechanism design problem.

In the case of our Surface-to-Air missile, let us suppose that for an instant it is disturbed from its flight path by a gust. The motion of the missile about its gyro will create an error signal, which is amplified and carried to its control surface actuating motor. This motor operates the surface, the position of which is constantly fed back into the controller. Rotation of the control surface (and the consequent return of the missile to its course) reduces the error signal from the gyro, which in turn reduces rotation of the control surface until the error signal vanishes and the system is returned to normal. When a signal from the ground is received, this is fed in as the new reference input and an error signal is generated, with the system functioning as outlined above.

It is a fundamental that the servomechanism is the product of a variety of factors that must be controlled and its design is determined by the magnitude and time variation of each of these factors. It is the last item in the design of a missile and can only be cre-

This system involves automatic direction of the missile along surface radar beam, which follows target in flight

ated after complete information has been obtained on the variation of such quantities as position, speed, voltage, current, force and torque with time and with each other. Each of these is a physical fact that exists regardless of the mathematical theories used and it is the problem of the mathematician to express these variations in formula, and thus the time-taking nature of servomechanism design. These quantities are usually complex and contain both real and imaginary parts. However, they may be plotted on three forms: the familiar rectangular or Cartesian coordinates, polar or exponential. The mathematics of servomechanism design, then, is the science of manipulating complex quantities.

Despite the variation in each of these quantities, it has been shown (Ref. 1) that the dynamic characteristics of any control system element may be expressed by a Transfer Function and the Laplace transform used in which the output ratio is determined assuming all the initial values are zero. This relationship can be expressed

$$O(s) = G(s)\, I(s) \qquad (1)$$

in which: O (s), Laplace transform of the output; G (s), the transfer function; and I (s), Laplace transform of the input. This may, of course, be written

$$G(s) = \frac{O(s)}{I(s)} \qquad (2)$$

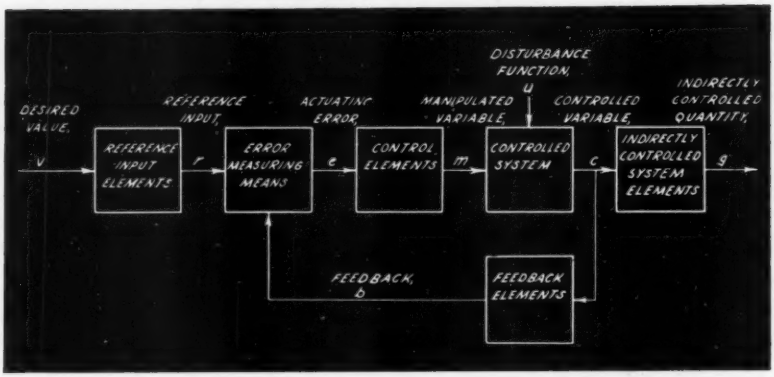
thereby defining the transfer function as the ratio of the output and input Laplace transforms.

In the past few years the transfer functions for virtually the whole range of variable mechanical actions have been developed and are already tabulated for servomechanism design purposes. Throughout these lists, it is clear that the physics of the individual mechanism determines its transfer function; whether it be a mechanical, electrical or hydraulic unit its action may be expressed by such a function.

From these lists it is possible to select a number of units which, although of widely varying physical nature, have quite similar transfer functions. Thus, when such a family of units is assembled, the servomechanism design problem is greatly simplified at the start. Proceeding from this initial tentative selection of components the next problem is to select one of the three possible types of control systems: (1) those in which a constant value for the controlled variable requires a constant actuating error signal, (2) those in which a constant rate-of-change of the controlled variable requires a constant actuating error signal, and (3) those in which a constant acceleration of the controlled variable requires a constant actuating error signal.

Fig. 1 is a schematic diagram of a representative feedback control system. The "desired value, v" is that value it is desired that the control system produce. The "reference input, r" may or may not be the same as the desired value due to the former's presence in the system. At the far right of the diagram the "indirectly controlled quantity, q" is the actual quantity that the system produces. The "controlled variable, c" is the output of the controlled system and is the quantity used to compare with the reference input. The "feedback, b" is obtained from the controlled variable but may vary from it due to feedback element characteristics. The "actuating error, e" is a signal proportional to the difference between the reference input and the feedback and comprises a signal to the control elements and the controlled system so as to actuate the controlled variable. The "manipulated variable, m" is obtained from the control elements and manipulates the control of the controlled system. The "disturbance function, u" is any undesired input to the system that affects the value of the controlled variable.

Fig. 1 Schematic diagram of representative feedback control system shows variety of elements needed to accomplish accurate control



The advantages of the feedback system can be seen in a comparison of its accuracy with a system without feedback, or an open-loop system. In the latter system, the controlled variable, C, is equal to the product of the transfer function, G, and the reference input R, thusly

$$C = GR \qquad (3)$$

which is a specific form of the general form of Eq. (1). Differentiation of Eq. (3) gives

$$d[C] = R\, d[G] \qquad (4)$$

Dividing Eq. (4) by Eq. (3) produces

$$d[C] = \frac{d[G]}{G} C \qquad (5)$$

Examination of Eq. (5) shows that a change in C is directly proportional to the change in G. The physical significance of this relationship is that the accuracy of the system is not any better than the accuracy of the controlled quantity. Thus, for the precise control necessary for the attainment of an accuracy of one percent or better, the variation in the transfer function cannot exceed one percent.

In contrast with this open-loop system, however, is the feedback system in which two transfer functions are present, one for the control system and one for the feedback circuit. Such a system may be expressed

$$C = G\,(R - HC) \qquad (6)$$

in which: H, transfer function of the feedback circuit. Eq. (6) may be solved for C as

$$C = \left(\frac{G}{1 + GH}\right) R \qquad (7)$$

Now, differentiating Eq. (7) and assuming that R and H are constants, gives

$$d\,[C] = \frac{(G)\,R}{(1 + GH)^2} \qquad (8)$$

Combining Eqs. (7) and (8) provides

$$d\,[C] = \left(\frac{1}{1 + GH}\right) \frac{d\,[G]}{G} C \qquad (9)$$

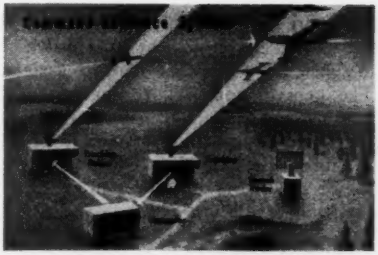
Study of Eq. (9) shows clearly that a change in the transfer function of the control system is equal to the percent change in the transfer function times the factor in parentheses. It is this factor that comprises the difference between Eqs. (5) and (9) and shows the greatly improved accuracy of the feedback system. The term GH is usually large, which reduces the parenthetical factor to a fractional amount. For ex-

ample, assume that H is equal to 1.0 and G is equal to 100. A change of 10 percent in the control system transfer function would produce a change of less than 0.1 percent in the controlled variable.

The accuracy and stability of a servomechanism system are mutually incompatible. Since increased accuracy requires response to smaller error signals, these must be amplified to increasing values. This signal amplification introduces delays in response time and thus introduces instability into the system which permits oscillations to build up to violent proportions in an extremely short period of time. Time delay can be reduced or eliminated by so-called "anticipatory" circuits, but these introduce additional complexities that must be weighed carefully against the improved accuracy resulting from their use.

Much of servomechanism design work is contained in studies of various proposed systems for stability. One of the methods employed is to locate by analytical or graphical means the actual position on the complex plane of each of the roots of the characteristic equation of the system. This is an extremely laborious method and the time required restricts its use to units having simple equations. A faster method is the use of Routh's Stability Criterion (Ref. 2), which involves only a simple algebraic process in its application to the coefficients of the characteristic equation of the system.

The most popular and widespread system of stability analysis at present is the use of Nyquist's criterion (Ref. 3) on a graphical plot of the open-loop response of the system as a function of frequency for a sinusoidal driving function. Nyquist determined that when the feedback signal is equal in magnitude and phase to the actuating signal instability will result.



Ground radar tracks missile and target in flight, computes collision course and transmits radio corrections to missile

The design of a servomechanism system may begin with the use of a "step" input, in which the voltage, for example, is zero and is instantaneously raised to a value of unity where it remains. The response of the system to this step input is then determined by use of the Duhamel integral. This rather crude method is effective for the analysis of "bang-bang" control systems and is useful as a preliminary check on a proposed design. It is inconvenient for detailed system analysis, however, since it requires calculation of the roots of the operational expressions. This steady-state analysis does not accurately interpret the dynamic functioning of the system. An approach to this problem is the use of a sinusoidal input to the system, which has the advantage of roughly approximating the dynamic characteristics of the system while retaining the simplicity of linearized equations. With a sinusoidal input, the output will be sinusoidal of the same frequency, although the amplitude and phase will be different. These latter two qualities are easily calculated, however. The Nyquist criterion may be used to test the system for stability and the graphs prepared for the test used to detect needed changes in the system.

These steady-state analyses, however, still do not accurately predict the dynamic response of the system and considerable effort has been made to reduce

the enormous amount of work required for complete transient performance analysis of a servomechanism system. The general approach to this problem is to use the Laplace transformation and the enormous amount of labor involved has been substantially reduced by the use of simulators and differential analyzers.

Another approach is to determine the steady-state response of the system and then to determine some correlation between this and the transient performance of the system. Such a method has been developed in Reference 4 and was derived from the inverse Laplace transformation. Simplest method presently available is the use of a series of charts which require no detailed calculations (Ref. 5). These charts relate the open-loop attenuation-frequency characteristics and the closed-loop response to either a sinusoidal input signal or to an input that is a step input of position.

Despite the rigorous mathematical methods now available for the theoretical design of servomechanisms, the presence of unwanted signals in the system destroys the classic linearities of the assumptions and renders the problem a purely experimental and developmental one. For example, amplifiers have finite capacities and when these are reached an increase in the input produces no change in the output and the amplifier is saturated. Actuators and power supplies are of limited power capacity and also can become saturated.

Further, they are subject to inherent nonlinearities, particularly hydraulic and pneumatic actuators, grab clutches and split field, series-wound electric motors. Backlash produces oscillations in a system which depend upon the servo loop gain, mechanical friction and material resilience. On-off signals create wide nonlinearities since they do not literally occur instantaneously. Most troublesome nonlinearity in a servo system is "noise," which can come from an infinite number of sources which are difficult and often impossible to detect. It is usually assumed that this extraneous noise has larger high-frequency components than the true signal and filters which pass only low-frequency components of any signal are used (Ref. 6). However, this system loses its effectiveness when the signals are large and rapidly varying such as during synchronizing operations.

The heart of most servomechanisms is the synchro motor. The set of three stator voltages transmitted from generator to motor contains all of the necessary information on the position of the rotor in the generator. A bar of soft iron placed in a magnetic field tends to align itself parallel to the field. However, it will have two stable positions 180-deg. apart. This is avoided by connecting the rotor winding of the motor to an a-c line, which renders it an electromagnet excited by alternating current and it is said to be polarized. Thus, it has only one stable position. The stable rotor position of the motor corresponds exactly to that of the generator. The rotor currents are only the small currents needed to magnetize the units. Any torques developed in the two synchros under static conditions are equal in magnitude and opposite in direction.

A variation of this system is the synchronous transformer, which is used with a synchro generator to indicate the difference between the angular positions of the two shafts. The transformer does not exert a torque tending to align it with the generator but, instead, it produces an error signal indicative of the difference in alignment between its shaft and the generator shaft.

The differential synchro, which has a cylindrical instead of a salient-pole rotor, is used to measure the sum or the difference between the angular positions of two input shafts. The differential synchro may be either a differential generator or a differential motor,

the latter including an inertia damper. The differential generator is normally used as an intermediate unit connecting the output of a synchro generator to the input of a synchro motor or synchronous transformer. Its purpose is to receive an electrical signal corresponding to a certain angular position of the generator, to modify this signal by an amount corresponding to the angular position of its own rotor and to transmit the modified electrical signal to the output synchro (Ref. 7).

The most important a-c motor presently used in servomechanisms is the two-phase induction motor. The stator coils are supplied with alternating currents equal in magnitude but 90 deg. out of phase. Such currents are obtained either from a two-phase power system or from a single-phase system by means of a phase-shifting circuit. The speed at which the flux rotates is the synchronous speed of the motor and for a two-pole motor operated by 60 cps. power, the synchronous speed is 3600 rpm. In a four-pole machine, the synchronous speed from the same power source is 1800 rpm. The speed of rotation of an induction motor is always less than this synchronous speed due to the necessity for relative motion between rotor and flux in order that voltage be induced in the rotor winding. The torque of the motor is controlled by varying the current that can pass through the transformer in series with the motor. The secondary voltage of the transformer is applied between the plate and cathode of an amplifier tube in the speed amplifier. When the error is zero, the tube is biased beyond cutoff and the secondary circuit is open so that very little primary current can flow. When an error in either direction exists, the bias voltage is changed and the tube is allowed to conduct. This conduction comprises a motor current, the value of which is determined by the error and the torque is increased proportionately.

The miniaturization program on vacuum tubes, the use of printed circuits and the process of "potting" complete circuit elements are well-known phases of the servomechanism development program.

It is clear that the guided missile is not the single unit weapon popularly supposed but is, instead, virtually a whole new field of human endeavor. The majority of the problems it has created have no exclusive connection with a destructive missile but are simply technical progress at an accelerated pace along familiar electrical and mechanical design lines. As a consequence, impatience with this nation's guided missile program is actually impatience with the whole gamut of technological progress, for there is assuredly no field of electronic, aerodynamic or mechanical scientific endeavor that does not have applications to the guided missile development program. Likewise, there are few developments in the guided missile field which do not have manifold applications throughout the general industrial field. As such, America's guided missile program is actually the sum total of America's scientific progress and, as a consequence, its pace can never be accurately criticized as slow. It is the inevitable, never-to-be-rushed pace of science.

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INDUSTRIAL MANAGEMENT AND THE ARMED FORCES

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graduated from the United States Naval Academy in 1924. He did post graduate work in naval and marine engineering at the U. S. Naval Postgraduate School and at the University of California, where he received a degree of Master of Science. He has had several engineering assignments afloat but during and since the war he has served mostly with amphibious and other commands concerned with joint operations. He has attended the Naval War College, the Armed Forces Staff College and the Industrial College of the Armed Forces. His last sea assignment was Commander Service Squadron One of the U. S. Pacific Fleet. He is presently on the faculty of the Industrial College of the Armed Forces in the Economic Mobilization Branch.

INTRODUCTION

The ability of the United States to develop and produce goods is credited as being our greatest asset in war. We Americans have brought about a revolution in warfare by our application of industrial potential to military needs. Our victories have not been won always by tactical superiority and some of our strategy may be found wanting under the critical eye of history. But our ability to produce equipment and to manage large supply lines has enabled us to apply the military principle of mass. This has ensured eventual success. Neither our enemies nor our allies seem to be able to imitate us successfully in this respect.

American military people now ply their trade in the same manner as their brothers in industry—by mass production methods. Our industrial brothers have the advantage as they apply these methods every day both in peace and war. A logical deduction would be that the industrialists may have something to teach military men; some of their theories may have purpose for the soldier, sailor and airman. If the philosophy of American industrial management which has produced a second industrial revolution is sound, it can have broader application.

Recently it was my good fortune while attending the Industrial College of the Armed Forces to become acquainted with the literature on theories and principles of organization as they relate to business and industry. I learned of such philosophers in this field as Frederick Winslow Taylor, Henri Fayol, Mary

Parker Follett, James D. Mooney and Alan C. Riley, L. Urwick and Luther Gulick; and from them of one military apostle, pleasant and readable General Sir Ian Hamilton. With this one exception nothing comparable exists in military literature to my knowledge. Therefore I would like to attempt an interpretation of how these philosophies might be applied within the present organizational structure of our Armed Forces.

I will review briefly the works of each of the writers mentioned and within the limits of my narrow experience I will try to show where modern industry has followed and has not followed their gospels. Finally I will point out where the Armed Forces may learn something of organization in their own fields from these teachers and from the practices in modern industry.

The science of industrial management may be said to have had its beginning in the United States in the decade of 1880 with the efforts by Taylor to increase the output of industrial workers. The period of his endeavor, from 1882 to 1915, coincided with a period of rapid growth in American basic industries. This growth and the passing of the strong personalities who were the original industrial leaders required new orientation in management. The management movement reached its stride in the decade of 1920 after the first World War had had a broadening effect on our industrial concepts. The subject of industrial management has received the attention of our universities and has resulted in various courses and in the publication of numerous text books. Today a knowledge of the principle of management is a primary requirement of industrial leaders.

FREDERICK WINSLOW TAYLOR[1]

Frederick Winslow Taylor is accorded the honor of being the founder of modern industrial management. Originally Taylor was a foreman in the machine shops of the Midvale and the Bethlehem Steel Companies. His background was the shop and mental approach to the problems of organization and management was from that position. In his first work, *Shop Management,* he propounded his principle of *functional foremanship.* He contended that few men who had all the qualifications demanded of a foreman could be found in the shop organization of his day. Taylor listed these necessary qualifications: brains; education; special or technical knowledge; tact; energy; grit; honesty; judgment; common sense; and good health. Men who had four or five of these qualifications, he claimed, rarely were found and those with six, seven or eight practically non-existent. One of these characteristics might cancel another in many men. His thesis was that the line or military type of organization, as he called it, should be abandoned for a specialist or functional type and that the foreman should be relieved of planning and other duties more or less clerical in nature. In place of the old line foreman there would be several specialists or *functional foremen* who were to assist and supervise the workmen in the various phases of a job. One would lay out the work, others would follow it through, inspect, keep machines in running order and maintain records.

The benefit from Taylor's *functional foremanship* was that it introduced needed specialization into the fast-growing American industrial organization of the later decades of the nineteenth century. Its drawback was that it violated a cardinal principle of good management—centralization of control or "unity of command." Most of Taylor's system of shop management had disappeared by 1920. It left many worthwhile heritages

among which were the repair and inspection departments and the position of assistant foreman. Its greatest contribution to modern industrial methods is the planning department.

Taylor pointed out the need for what he called the *exception* principle in management, a term which is still in general use. Because of both human and time limitations, only summarized and comparative reports should reach the executive. Such a report should cover the elements of the problem, and point out *exceptions* to past averages, both good and bad. Industry and business have generally followed this exception principle of Taylor's and today are decentralized much more than government or military organizations. Without the principle of decentralized responsibility, it is unlikely that our large corporations and industrial establishments could have reached their present size and efficiency.

HENRI FAYOL[2]

Henri Fayol, a Frenchman and a contemporary of Taylor, was another prophet of industrial management, but in striking contrast with his American counterpart. Fayol was a successful manager of a large coal and iron company for many years. His mental approach to the problems of organizational management and administration was from that position. His papers were recently translated into English but his tenets have been known to students of these subjects in the United States and Great Britain for many years, and they have been long established in industrial organizations in France and in the Latin countries. Except for papers presented before engineering and scientific groups, he did most of his writing after he retired and only the first half of his primary work, *Administration Industrielle et General,* was completed at the time of his death in 1925.

Fayol defines the functions of management as:

1. *Foresee* and *Provide* (Planning)—Examining the future and drawing up a plan of action.

2. *Organize*—Building up the dual structure of men and material in an undertaking.

3. *Command*—Maintaining activity among the personnel.

4. *Coordinate*—Binding together, unifying and harmonizing activity and effort.

5. *Control*—Seeing that everything is in conformity with the established rule and the expressed command.

Fayol indicated the limitations of the human mind in its capacity to control other human beings. Another Frenchman, Graicunas, developed this, calling it the *span of control.* The latter pointed out that difficulties of control increase not directly with the number of subordinates, but in a geometric ratio of all the possible relations among them. Fayol showed that lines of authority actually are only the sides of an *organizational ladder* and that there are horizontal relationships or rungs of the ladder, equally important as the vertical relationships.

Other factors in Fayol's thinking are of interest to the military man. He considered that centralization (or decentralization) is neither good nor bad in itself, but depends on the circumstances of the situation and the ability of the controlling personnel. In none of his organization charts did he propose a general staff structure such as has been adopted from the Army by American business organization. Fayol realized the importance of nonfinancial incentives, such as we are fortunate to have in the armed services but which American business men generally have neglected.

JAMES D. MOONEY AND ALAN C. RILEY[3]

James D. Mooney and Alan C. Riley, both American industrialists, have made the most synoptic presentation of the organization and management problem from the American point of view. Their work, *Onward Industry,* was first published in 1931 and is now out of print. A condensed revision was published in 1939 under the title *The Principles of Organization.* Six printings of this have been issued. The latest, revised in 1947 by Mooney who served as a Captain in the U. S. Navy in World War II, incorporates the lessons learned during and since that war. Mooney and Riley clearly indicate the difference between the *scalar*[4] or *line* principle and the *functional* principle[5]. They also developed the proper position of staff service with the compulsion of leaders to use the advice of their staffs and the corollary of the necessity for staff independence.

A major contribution of Mooney and Riley to the study of organization is their excellent analysis of the historical examples in the ancient, medieval and modern worlds. Especially important is their examination of the *general staff* principle in Army organization and of the centralized organization of the Roman Catholic Church with its line and functional structure and staff organization. They indicate how the better features of military and church organization can be applied in industrial activities.

The theories of administration as expressed by Mooney and Riley, and the definitions of the organizational terms which they adopted, are difficult for the uninitiated to understand. Urwick, whose work will be discussed later, does a much better job in this respect.

MARY PARKER FOLLETT[6]

One of the most stimulating of the industrial philosophers and certainly one of the most unusual was Mary Parker Follett. She never engaged in business and held only minor positions in government but she was nevertheless a political and industrial thinker of the first rank. Her philosophy has a psychological flavor; and while many of the theories which she expounded have application in labor-management relations and in government, most of them have either long been applied or have no place in military organization.

Her philosophy is best summarized by the title of the book containing her collected papers: *Dynamic Administration.* The subjects of these papers, delivered as lectures between 1925 and 1932, indicate the scope of her thinking: "Power," "Giving of Orders," "Constructive Conflict," "The Psychology of Control," "The Psychology of Conciliation and Arbitration," "Leader and Expert" and "Indoctrination in a Planned Society." Of most interest to us is her *Law of the Situation.* Miss Follett's thesis is that in complex modern society it is the situation which *controls;* the true leader *responds* immediately and effectively to that situation. Since it is the situation that is primary, function in organization is more important than position and authority should therefore be derived from function rather than position. Responsibility should be "for" and not "to"; leadership should be, in so far as conditions permit, functional rather than personal.

L. URWICK[7] AND LUTHER GULICK[8]

In addition to these earlier pioneers in a philosophy of organization for industrial endeavor, there are certain present-day proponents of a science of administration which can be equally applicable to business, government or any human enterprise. The leaders of this movement are Luther Gulick, an American authority on Public Administration, and L. Urwick, an English management consultant.

Urwick presents a better picture of the whole organizational problem than any of his teachers. In his volume, he reviews the various theories and includes a table in which he lists the principles as he has defined them, and parallels them with the applicable statements of the authorities. His short work is believed to be the most comprehensive in the field and it is recommended that it be read first.

Urwick defines the conflicting principles confronting members of any organization: Duty and Responsibility versus Power and Authority. He lists the three methods of organizing:

a. By numbers or areas (unity method)

b. By steps (serial method)

c. By types of operations (functional method).

The unity method of organization is the most common and also the most understandable. Examples, both ancient and modern, are numerous, from the Laws of Moses and the Roman Legion to the modern nationalistic state. Army organization is, to a large extent, built upon the unity method. In the Navy afloat, we have our divisions, squadrons, wings and flotillas so organized; in the shore establishment, Naval Districts. American mass production industries, for the most part, are organized by the serial method. Examples of this type of organizing in the military service are few—but an assault amphibious operation is one. With organizations becoming more complicated in modern society, it is necessary to go to the functional method more and more, but this method is the most difficult to define and coordinate. Under the unity and serial method of organizing, the limits of authority are usually well defined, whereas the functional method requires intervening relationships. The type-and-task system[9] of the U. S. Navy is an excellent example of the use of the functional method in a military organization.

Urwick outlines the various types of relationships that must exist in any complex organization. These are (a) *line* or vertical; (b) *lateral* or horizontal; (c) *functional;* and (d) *staff.* Line relationships are always formal. Lateral relations must be informal. Functional authority has to exist side by side with line authority, and the relationships involved are usually informal but better understanding will result if they can be in some measure formalized. Staff relations, in which one acts or directs for a superior, are most difficult. Friction is inevitable unless staff relationships are formalized or explained carefully to all concerned.

Luther Gulick, the present American exponent of the science of administration, is primarily interested in its application to government; however, his theories on organization are equally applicable to industry and to the military. Because the words "administration" and "management" have lost most of their special content, he uses a short title for grouping of the elements in the work of a chief executive. POSDCORB is an abbreviation for Planning, Organization, Staffing, Directing, Coordinating, Operating, Reporting and Budgeting.

Gulick's recent work *Administrative Lessons of World War II* should be read by senior officers of all the Armed Services.

THE INDUSTRIAL PHILOSOPHERS AND MODERN INDUSTRY

It is interesting to compare the backgrounds and approaches of the various original thinkers on the subjects of organization and management. Taylor's viewpoint was always that of the minor executive. He concentrated on the practicality of the problem. Mary Follett, an outsider, approached it from general principles, whereas Fayol, the successful executive, indicated clearly the framework on which sound management is built. James D. Mooney has given us the viewpoint of the present day, whereas Ian Hamilton whose work has not been summarized here[10] has given us the only classic on military administration. Finally, there are Urwick, the Englishman, and Gulick, the American, who endeavor to tie up all the loose ends and compose a science from these expressed principles.

The practical and pragmatical aspects of these philosophies have been incorporated into modern industrial methods. Growth and competition within industry have necessitated this. In the field of personnel relations, however, much of it went unheeded until the workers, organized into labor unions, taught industry in bitter lessons many of the truths these industrial philosophers had expounded.

American industry in its top organization has been adopting more and more the general staff principle of the U. S. Army. This has been hastened by the contacts which industrial management had with military officers in both World Wars, either within the services themselves or in the production of war materials.

Industry adopted the *exception* principle of management outlined by Taylor, and also the workable aspects of his functionalism and decentralization. Through these, large scale decentralization has been possible. Functionalism has been accepted throughout the whole American economic structure as is evidenced by the way sections of industry depend upon one another. European industry, on the other hand, is still a collection of units, following, in general, the precepts of Fayol.

Realistic American business has accepted the *Law of the Situation* advanced by Mary Follett. Nowhere else in American life is the situation, rather than the personality, so much the dominating factor. Authority is diffused. Control is no longer in men, but in methods, as is indicated by such terms as budget control, inventory control, and quality control. Coordination, both external and internal, is the guiding principle. Even competition, to an extent, has been coordinated and American business has been freed thereby from the strangulating effects of cartel.

In one important respect, industry has not followed the teachings and warnings of its philosophers. It has not been able to police itself. It has failed to include a component in its organization similar to the judiciary in civil government. Mooney points out that the ancient man, especially the Roman, was able to incorporate the executive and judicial functions within the same person. Western man has not done this; the judge has always been separated from the executive. Modern industry, with its early laissez-faire, and later rapid expansion, developed the executive function to a marked degree but ignored the judicial function. As a result, government with its regulations and the worker with his labor unions, have moved into this void.

APPLICATIONS OF PRINCIPLES OF INDUSTRIAL MANAGEMENT TO MILITARY ORGANIZATIONS

Industry has learned much about organization from the military. Prior to the development of modern industry, military and naval units were the only large secular organizations devoted to a single purpose. Many of Urwick's and Mooney's precepts are based on military examples. It may be opportune now for industry to repay this debt by offering the military some of its own tested principles. Our industrial potential is our greatest military asset. In World War II, the output of our mass production techniques literally smothered the enemies on every front. Military and naval organizations in themselves have become mass production complexes, products of our industrial capacity. Senior officers controlling such complexes have had to become more managers than commanders. The Services have become more unified, not through the force of law but because the complexities of modern warfare has forced it upon them. Things have to get done as much by mutual cooperation as by order. Integrated units such as ships and infantry companies are swallowed up in larger and highly complicated organizations. Functionalism and specialization have had to be accepted, and cooperation and coordination no longer can be formalized within a tight command structure.

Industry has one advantage not available to the military. An industrial organization is daily performing the function for which it was founded and the soundness of its organization policy is being tested constantly. Mary Follett's *Law of the Situation* is hovering over American business and industry every day. On the other hand the soundess of any military concept or organizational principle can only be given its final test in war. The hardest job that a military officer has in peacetime is to remain realistic and not let himself fall into a subjective viewpoint on any problem. He should always pay heed to the "devil's advocate" either within or without his Service. He should constantly be looking for some base line with which to compare his position. Modern American industry offers to the military officer such an opportunity.

The writer, being a Naval officer, can only express a circumferential view with respect to the Army organization. He must be careful of his criticism and the comments herein are offered here for whatever the reader may think they are worth. The Army has good line and staff principles and proper staff procedures generally are recognized by Army Commanders—a condition that is not always found in the Navy. As stated heretofore, industry has copied many of these principles and has had success in their application. The Navy has done so only grudgingly. On the other hand, the organization of the Army to a Naval officer, does not seem to be sufficiently flexible. Functions are compartmented into formal branches and the rigid structures of the General Staff is adhered to with almost religious fervor. The Army Service Force and the Operations and Planning Division in the Office of the Chief of Staff, institutions adopted during World War II, are now gone and the Department of the Army is again back to its old four sections in the General Staff. The term *general staff* through over-use, has lost its meaning while the General Staff itself has grown to such an unwieldy extent that each section needs a staff of its own—organized of course on the four-section basis. American business had better guard against allowing the line and staff principle of organization to become an end in itself.

The Air Force presently seems to be in an organizational dilemma. For a highly mobile force, operating in a most fluid medium, it has inherited the tight

command structure of the topography-bound Army. It appears that the Air Force could apply the Navy's type and task force system[11] and its concept of operational and administrative control. Operational mobility and administrative supervision could be maintained thereby without the frequent reorganization or changes in assignments which is plaguing the Air Force today.

Unlike the Department of the Army which has gone through several major reorganizations during the past fifty years, the present-day organization of the Navy Department is the result of empirical change and growth, with increased stimulus during war. It may need pruning but the primary lesson in organizational methods that the Navy can learn from the industrial philosophers, from American industry and from its sister service, is a better understanding and acceptance of functional and staff principles. Most senior naval officers were brought up in an organization composed of a relatively small number of highly integrated ships, responding promptly to the will of their commanders. New naval units are numerous and naval organization has become complex. Large staffs are necessary to assist the commanders. Functional as well as command responsibility have to be adopted. Recently, senior naval officers recommended against formal adoption of the general staff system within the Navy, although there has been a gradual growth of such a system since the establishment of the Office of the Chief of Naval Operations in 1915.

The Navy type-task system is an excellent demonstration of military functionalism[12]. There is a considerable amount of functionalism within a man-of-war but it has been the product of such slow growth that it is hardly recognizable. Despite the above, the problem of integrating functional control with line command is little understood and grudgingly accepted in the Navy, especially by the non-specialist line officer. Nevertheless, functionalism has made great strides within the Navy. Naval aviation was the first great functional movement that penetrated the entire naval establishment. There has been increased emphasis on specialization in the officer grades and the difference between staff corps tend to become more functional than professional. Within the line, there are now engineering duty, special duty and limited duty officers. The new functionalism is also evident in amphibious operations, in the naval supply organization and in naval base development.

The Navy has yet to adopt formally such fundamental organizational tenets as the *span of control* of Fayol, or the *exception principle* advocated by Taylor. Trained in ships whose organizational development has been going on for centuries, many naval officers believe in maintaining the same measure of control in the more loosely organized groups which comprise the Navy today. Successful Captains sometimes have been found wanting in the Flag Rank, probably for this reason.

CONCLUSION

This all leads to the conjecture that command is becoming something of an anachronism in complex modern military organizations. The executive function now is more that of a manager than a commander. The Navy has recognized command limitations by dividing it into operational and administrative control with respect to the Operating Forces and by establishing command components as outlined in General Order Number 19 within the Shore Establish-

ment. Many of the Air Force's present organizational troubles may be due to its use of a too rigid command structure. The Army still applies the title "Command" to administrative units but there is relatively little direct command exercised anywhere except in the actual combat area. Much as we hate to admit it, military officers *manage* these days rather than ***command.***

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ADVANCES IN AIRCRAFT STRUCTURAL DESIGN

ACKNOWLEDGMENT

This is an abridged version of a paper presented by MR. G. T. R. HILL at the third Anglo-American Aeronautical Conference on September 4, 1951. It is reprinted from "Engineering" for October 26, 1951.

To keep this paper within reasonable limits, there are many aspects of structural development which have been omitted; for example, the technique of full-scale and model testing, dynamic loading, fatigue and temperature effects on the strength of materials, shear lag, the effect of cutouts, and diffusion problems.

The Wright brothers achieved success in powered flight firstly by their experiments from which they found that they could get enough lift; secondly, they grappled successfully with the problem of providing quick-acting and powerful controls; thirdly, they built a reasonably satisfactory structure; fourthly, they produced a propulsive system light and efficient enough to get themselves off the ground. Their success in achieving fully controlled flight with a human pilot inspired most of the aeronautical world to develop along the lines into which their own design had settled down. Wood was the material chiefly used, and high-tensile steel wire was available for the tension members. These early structures were relatively large with very light loads upon them, and the low density and high specific strength of wood were just what was wanted. Bamboo was often favored for struts owing to its natural tubular shape with stiffening diaphragms at suitable intervals. Fittings were commonly made of mild-steel sheet, and string and glue were often used to prevent the wooden members from splitting. Fabric of various kinds covered the wing surfaces; waterproof paper was not unknown as a wing covering, its virtue being eloquently expressed in one of the early Avro catalogues in these words, "True it is cheap, but then it is easily repaired."

In the early years of the century, France was the center of the most active development with biplane design led by the Farman brothers and Voisin, and monoplane design led by Blériot. These monoplanes were all fitted with external bracing wires, as fitted half a century before by Henson, and it became clear that it was more difficult to design a light monoplane structure. Some of the Blériot designs were loaded to over 4 lb. per square foot, whereas the corresponding figure for biplanes was below 3 lb. per square foot. The reason was that the wing structure must be capable of carrying down loads as well as up loads. With a wire-braced

structure, such as that used on the early monoplane wings, this results in a depth of girder to carry the lift loads equal to the spacing between the lift-wire attachments and the main spars, on top of which must be placed the girder of a depth sufficient to carry the anti-lift wires; there was a tendency to economize in the depth of the monoplane structure, which resulted in higher tension and compression in the members, and consequently a heavier structure.

By about 1913 there was a growing number of fatalities due to the structural collapse of many monoplanes; in many cases there was evidence that the wings collapsed downwards. The War Office, the chief buyer in this country, lost confidence in the monoplane as a type. This had a profound influence on the trend of design in Great Britain, which was one of the last of the great designing countries in the world to abandon the biplane type. If a saving in height between the points of attachment of the lift wires and the anti-lift wires had to be made, it seemed common sense to effect most of the saving on the "cabane" carrying anti-lift wires, because it was felt that these wires did not really do much except hold the wings up when the aircraft was on the ground. In many designs, therefore, the angle of the anti-lift wires was very flat. With the highly cambered wings in use in those days, the moment due to camber was relatively large, so that, under a down gust, the wing structure would twist sufficiently to produce a further downward load, and so on until disaster supervened; nowadays, this is described as "divergence."

Increasing engine reliability and the introduction of multi-engined aircraft reduced the frequency of forced landings, with the result that wing loadings experienced a steady increase, and it became economical to use metal to replace heavily loaded wooden members; steel-tube fuselages, the forward ends containing the engine and crew, came into wide use before the First World War. Aluminum was still confined to structurally unimportant parts, such as fairings and cowling panels over the engine. At that time, fabric seemed an excellent material for producing wing shape of the right contour, both from the point of view of air flow and for transferring air loads on to the primary wing structure. However, with increasing air speeds and higher wing loadings, fabric failures began to occur in the air. One of the earliest attempts to provide a metal skin was made by Junkers, in Germany, who experimented with a highly corrugated steel skin which was only a few thousandths of an inch thick. With the coming of suitable alloys of aluminum, the smooth skin covering of today came into almost universal use.

The Short Silver Streak of 1921 was the earliest example in Great Britain, and, it is believed, in the world, of the completely all-metal structure; the spars were of tubular steel and the wing skin was non-structural. Junkers built a number of aircraft in which the aluminum skin was corrugated in the line of flight, and was thus an effective equivalent of all the rib flanges. Running the corrugations lengthwise was not directly admissible, for obvious aerodynamic reasons, but with frequent internal longitudinal stringers a comparable result was obtained. The Junkers corrugated skin was applied to the fuselage covering as well as to the wings, which were of the multi-spar type, fully cantilevered; the spar booms were tubular, with lattice bracing between top and bottom booms.

Fabric stitched on ribs had many advantages; although the ribs underneath caused noticeable ridges, they were along wind, and with care in design and construction the sections downwind of a fabric-covered wing were quite good. In the ingenious "geodetic" construction due to Wallis, the members supporting the fabric all ran diagonally;

the aerodynamic loss was tolerable at the cruising speeds, below 200 knots, of the Wellington, which was largely used during the Second World War. As soon as fabric was abandoned, the difficulty of producing a surface free from waviness along the wind direction had to be faced.

The earliest use of sandwich construction, in which an inner and outer strong skin are stabilized by a very light core which spaces the skins well apart and increases the stiffness of the panel, is believed to be in 1925 on the author's Pterodactyl Mark I. In this a special ⅛-in. plywood was constructed of outside birch veneers ⅟₁₀₀ in. thick; with a balsa core ⅟₁₀ in. thick; this was used on the sides of the fuselage. Much later the technique was widely adopted, notably in the de Havilland Mosquito. Whether it is possible to adapt this technique to metal construction is a question as yet unanswered.

With increasing demands for torsional stiffness, thicker sheeting can be used at the top and bottom surfaces of wings, where there is a large concentration of load; the stringer spacing may become very close, and serious attention is being given to extruding skin panels with integral stringers. When skins are thick enough to be extruded, as in many designs today, the idea of machining them so as to be smooth enough to ensure laminar flow is attractive. Smoothness requirements with limitations on waviness measured in thousandths of an inch, are apparently almost impossible to achieve. On a small scale a suitable surface has been produced, but only as a result of many weeks of hard work on a few square feet. The dividends in speed and range for getting a really smooth surface, however, are greater than any other gains which the structural engineer has in sight; reinforced plastic construction offers attractive possibilities.

It is by no means always true that the design of an aircraft with a lower structure weight percentage is better than that of a rival aircraft with a higher value, particularly on long-range aircraft, where the percentage fuel weight is high. Compare two aircraft designed for the same duty with different spans: normally, the large-span aircraft wing would be heavier than that with the small span, but owing to the reduction of induced drag with span, the fuel load for a given range would be less, and it might well be that the all-up weight of the large-span aircraft would be less.

The square-cube law states that for geometrically-similar aircraft with constant wing-loading and factors of load and safety, the wing area, and therefore the all-up weight, increases with the square of the linear dimension while the structure weight increases with the cube; therefore the structure weight percentage must increase with size. If true, this puts a definite limit on size if any useful load at all is to be carried. In the early days, an aircraft weighing 5 tons was estimated by one well-known authority to be the biggest that could just leave the ground, carrying no useful load at all. Nowadays it has become clear that other factors of comparable importance were neglected by the weight estimators of old. Only an unexpectedly small fraction of the structure weight is really doing the work of an ideally stressed structure. On large aircraft it is easier to refine the design of non-structural parts.

In 1949, Keith-Lucas showed that, whereas at some fairly large all-up weight the landplane and seaplane came

neck-and-neck, at higher weights the seaplane showed a saving in weight compared with its rival. The land undercarriage is a structure in which the loads and stresses can be fairly accurately assessed; it would thus tend to follow the square-cube law, and hence its percentage structure weight would increase with size; on the other hand, the seaplane hull is a structure which can be progressively refined with increasing size, and the square-cube law therefore applies to a small fraction of its weight, thus giving it an advantage in large sizes over the landplane undercarriage.

With the advent of jet-propelled aircraft there has been a sudden increase in speeds and cruising heights. When flying in disturbed air, speed is a major factor in producing gust loads, the additional load being roughly proportional to the speed of the aircraft entering the gust, assuming a constant wing loading. It is now possible to fly high enough to encounter the turbulence which is associated with jet streams, where wind speeds relative to the earth of upwards of 200 mph. produce a high rate of wind shear, and corresponding turbulence. There is, however, no indication to the pilot by visible cloud. By fitting velocity-acceleration recorders and recording accelerometers to large numbers of aircraft, it has been possible to build up a considerable volume of statistical evidence which defines the kind of gust in the lower height range, say up to 20,000 ft., and also the frequency of gusts of any given severity. In order to be sure that the structural strength of an aircraft is adequate for the kind of gusts which may be met at 30,000 ft. or 40,000 ft., however, it is necessary to go to these heights and measure the gusts which are to be found there; work on this task has been undertaken since the Second World War. The earlier results in Great Britain confirmed the belief that, on the whole, the air is much calmer at these high altitudes, particularly if flying in relatively thin layers of disturbed air is avoided; but at least one case is on record of alarmingly high accelerations at high altitude measured on a day when a jet stream was present. The present design requirements for gusts are admittedly based on guesswork.

While accelerations produced by gusts act in any direction, it is only the accelerations produced by changes of lift on the wing that are serious from the point of view of both structural safety and passenger comfort. To reduce these accelerations, the slope of the lift curve must be reduced, involving a loss of stability and a loss of maneuverability of the aircraft. The various arrangements proposed for reducing the slope of the lift curve consist essentially of a detector to measure the gust, a device, usually a flap, to alter the lift on the wing, and a servo-motor to amplify the signal received by the detector to an extent sufficient to operate the flap. The whole apparatus must produce the answer in a small fraction of a second. Since some aircraft now have power-operated ailerons, it is attractive to explore the possibility of coupling these up to the detector so that both ailerons move in synchronism when a gust is met. From the point of view of structural safety alone, it would be sufficient to "cut off the top of the lift curve," and the mechanism would then act only when the danger point was approached. It would be preferable, however, either to flatten the slope of the lift curve all along its length or to reduce the slope considerably over a

limited range, leaving it unaltered outside this range. There are many problems to be solved: the degree to which the lift-curve slope can be safely reduced, the amount of lift reduction at which it is useful to aim, the acceptable time lag, and whether it is possible to reduce the lag sufficiently with such large surfaces as ailerons, or whether much smaller surfaces, which could easily be moved much faster, would be effective. If the gust-alleviator could be developed to such a pitch that its reliability was comparable with that of the aircraft-control system (a by no means impossible task) then for a given load factor and factor of safety, a lower structure weight might be justified with the gust-alleviator in action.

The common manifestations of aeroelasticity in flight may be conveniently divided into the non-oscillatory and oscillatory types. Perhaps the simplest and most familiar of the first group is the progressive loss of aileron control with increasing speed of flight. If the speed increases sufficiently a point is reached at which the movement of the control surface has no effect at all on the aircraft; above this speed the effect of the controls is actually reversed, this critical change-over being known as the "reversal speed." A given angle of aileron produces a given change in pitching-moment coefficient on that part of the wing affected by the aileron itself. Under this pitching moment the wing twists elastically, and always in the opposite sense to the motion of the aileron; a down-going aileron produces a loss of wing incidence, and thus the lift due to the aileron is diminished by reason of the wing twist. This loss in aileron effectiveness increases with the square of the speed, and at the reversal speed it overcomes the additional lift which the pilot intends to get by moving his aileron. The pilot has a continuous warning of the approach of aileron reversal as he increases his speed; sufficient torsional stiffening of the wing structure will postpone the reversal speed.

If a straight wing of conventional construction has a symmetrical section, its center of pressure at the quarter-chord point will be somewhat in front of the flexural axis. The lift force in flight will then twist the wing in the direction of increased incidence with a resulting increase of lift. If now the angle of incidence is suddenly altered, say by a vertical gust, then the twisting moment on the wing will be proportional to the square of the forward speed; since twisting is resisted by the constant elastic stiffness of the wing in torsion, it is easily seen that if the forward speed of the aircraft is increased sufficiently these two effects will become equal. At that speed, the divergence speed, the wing twist can become theoretically infinite. Fortunately the divergence speed is usually well beyond the range of flying speeds of present-day aircraft.

The simplest examples of flutter involve motion in two modes at the same frequency, with a phase difference between the modes; this phase difference enables energy to be extracted from the air stream, and if the extraction of energy exceeds that dissipated by the damping, both structural and aerodynamic, then the motion builds up in amplitude until the structure collapses. Sometimes the motion involves more than two degrees of freedom, but never less, except in cases where, for example, there is a movement of a shock wave, and the motion is no longer of the simple-harmonic type. One of the first well-authenticated examples of flutter occurred on the tailplanes of the twin-engined Handley Page 0/400 aircraft built at the beginning of the First World War. The rear end of the fuselage and the attached tail surfaces formed an oscillating system with two degrees of freedom; in one mode, the port and starboard elevators could oscillate about

their hinges 180 deg. out of phase, the relatively weak spring restoring force being provided by long flexible control cables through which each individual elevator was connected to the pilot's control column. In the other mode, the tailplanes and rear end of the fuselage could oscillate in torsion, and the possibility of a phase difference between the two modes of oscillation was diagnosed as the cause of flutter. The cure proposed was simply to cross-connect the port and starboard elevators, so as to synchronize their movements.

The effectiveness of mass balance in preventing oscillation involving the control surfaces is now well established. The oscillation is a binary one with rotation of the control surface about its hinge and either translatory motion of the surface to which it is attached in the direction perpendicular to the line of flight, or torsion of this surface, giving rise to incidence changes. The weight penalty attached to mass balance is of the order of ½ percent of the all-up weight, both for small and large aircraft. It can, therefore, appreciably affect the payload of a long-range aeroplane; mass-balancing is, however, one of the most reliable devices ever fitted to an aircraft.

With the advent of speeds of flight near, and even surpassing, the sonic speed, the provision of adequate wing stiffness often involves appreciable increases in structural weight. The appearance, or the reappearance, of aircraft with highly sweptback wings has accentuated the aeroelastic difficulties which the designer has to meet. On the straight wing, bending and twisting can be controlled separately. The twist produces change in incidence and therefore in air load; bending produces no change of incidence and thus the air load on the wings is independent of their bending flexibility. With a swept-back wing, both bending and twisting produce changes of incidence. Much study at the present time is being given to the exact modes of distortion of the swept-back wing under lift loads. When the wing tips bend up there is a loss of incidence and when the wing twists there is a change of incidence in the same sense, although different in amount from the change of twist, depending on the angle of sweepback.

Consider an increase of incidence along the wing such as that encountered when meeting an up-gust. Upward deflection of the wing tips as compared with the wing root will produce a loss of incidence at the tips, with a resulting nose-up moment on the whole aircraft. This nose-up moment rotates the aircraft to yet higher incidence; in other words, a condition tending towards instability is experienced. It is also clear that the whole effect is proportional to the wing flexibility in bending. High speed appears to demand small wing thickness and high sweepback; the maintenance of longitudinal stability calls for high thickness and small sweepback. The users of the aircraft call for low structure weight; it will be interesting therefore to see what kind of solution to these various conflicting requirements the future will provide.

Some fifteen years ago, the general layout of aircraft seemed to be reaching a degree of stability appropriate to the dignity of a well-established art, whereas now the design of high-speed aircraft has changed and is changing rapidly. By the time the Second World War was over, Lippisch in Germany had brought on to the drawing board the delta design, where the very heavy sweep of the leading edge is associated with little or no sweep of the trailing edge. In some ways, such a design eases the task of the structural engineer, who would perhaps regard as ideal square or circular plan forms, with reasonable depth in the center. The delta wing has a smaller span and aspect ratio than is usual and thus, in general, less bend-

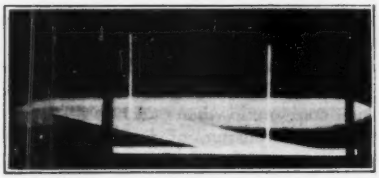


FIGURE 1.

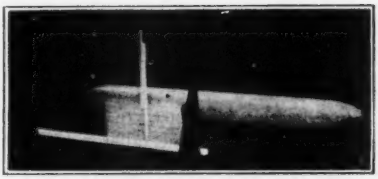


FIGURE 2.

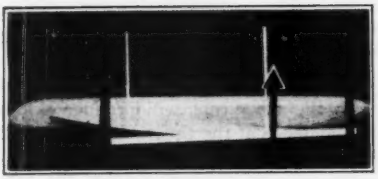


FIGURE 3.

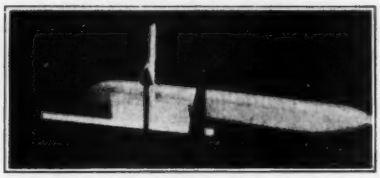


FIGURE 4.

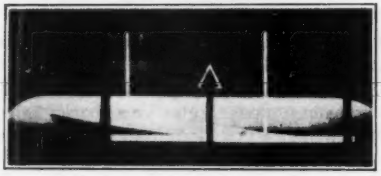


FIGURE 5.

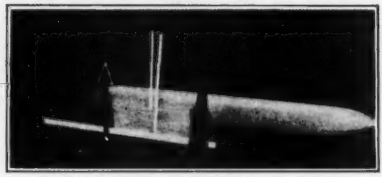


FIGURE 6.

FIGS. 1. TO 6. AERODYNAMIC AND STRUCTURAL DISTORTION OF SWEPT-BACK WING.

ing moment. In addition, with the same thickness/chord ratio, the absolute depth in which the main spars are housed is greater, since the root chord is large; questions of torsional stiffness are eased by the area towards the wing root of what may be called the torsion box.

Large span, which favors the reduction of induced drag, is costly in structure weight as the sweepback becomes more pronounced. One of the many enemies of low wing-structure weight is the stiffness required to ensure freedom from control reversal, flutter and adverse movement of the aerodynamic center due to wing distortion. Control reversal arises basically from the added load due to control-surface movement acting near the half-chord point, while added load due to incidence changes acts near the quarter chord. The wing structure must be both strong and stiff enough to deal with loads applied at either point; if these two points of application of load could be brought closer together, less structural stiffness would be adequate for safety at a given speed of flight. One way of tackling this problem is to consider types of control which, when they are moved, do not bring in their train such backward points of application of added load, such as increasing the control-surface chord, and the use of the spoiler control. If the drawbacks of either method could be diminished sufficiently, the span for greatest economy might be increased if flutter and shift of aerodynamic center due to distortion could be looked after.

The loss of incidence hitherto inseparable from the upward bending of a swept-back wing is the primary cause of the latter trouble. In the past there has been some confusion between structural twist and incidence change, which for straight wings are identical. The photographs reproduced in Figs. 1 to 6 show the distortion of a swept-back wing loaded in two different ways from two points of view, that of the aerodynamicist who is interested in the tip incidence, as measured by the transparent grid, and that of the structural engineer who looks along the length of the wing from tip to root and studies the twist by observing the alignment of the two pillars, inboard and outboard, mounted at right angles to the local wing chord. Figs. 1 and 2 show the wing under no load, with zero incidence change from root to tip, and zero twist. Figs. 3 and 4 show that when the wing is loaded at the arrow, which is on the flexural axis, there is no twist, but there is a loss of incidence due to bending. The aerodynamacist would like to see the wing distorting under load into the shape shown in Figs. 5 and 6, where the arrow showing the loading point is in front of the flexural axis. Here, there is no change in tip incidence, although there is some structural twist. If such a wing could be designed, and the flutter problem solved, it might be possible to avoid the increase in torsional stiffness and structure weight usually demanded by sweepback.

Turning to the formidable problem of landing aircraft of heavy sweepback, it has long been known that the slope of the lift curve falls off as the aspect ratio is reduced, and that the maximum lift with low aspect ratio is developed at angles of incidence higher than those in common use; even when the maximum lift is reached it attains only a modest value which it is difficult to raise by flaps or other means, especially when account is taken of the need to trim longitudinally. There may be serious difficulty with the lateral stability at the lower end of the speed range, at any rate with the less extreme angles of sweepback; furthermore, the rapid increase of drag as speed is lost in the approach to land means that any attempt at putting the aircraft on the ground after an engine failure would be hazardous.

One possible solution would be to hinge each wing about a vertical axis, so that in the landing configuration the wings are projected more or less at right angles to the plane of symmetry, and in the high-speed configuration they are swept-back to give the delta shape. This would appear to lead to formidable structural problems. Preliminary examination, however, suggests that, on the whole, there would be a net gain. Apart from complication, the penalty in structure weight is likely to be quite small. Many years ago, the author had some experience of sweepback variable in flight with the Pterodactyl Mark VI. The range of sweep-back was much less than would be needed in the application now under consideration; the variable sweep was delightfully easy to operate in flight, and the structure weight penalty was only 2 percent of the all-up weight. On the modern version where large angles of sweep will be needed, great ingenuity will be called for in making good the cracks and gaps near the hinge, but the whole philosophy of a change in geometry to deal with the immense speed range foreseen for this kind of aircraft is in line with what has been done with success in the past, namely, the high-lift flap, retractable undercarriage and the variable-pitch propeller.

These speculations on the shapes into which aircraft may change in the course of the next few years have as their main object the stimulation of discussion and experimentation. Looking back over a period of nearly fifty years since the Wright's first demonstrated the pos-

sibility of human flight, one of the many lessons which emerges is that progress comes in two ways—by steady methodical development, and in gigantic bursts when a new idea is born, is at first laughed at, is then taken seriously, and, finally, sweeps the board. The present is a time of ferment, of galloping progress in the world. As a distinguished former President of the Royal Aeronautical Society, Dr. Roxbee Cox, has said, some ten years ago, "We must have ideas, develop them and use them. Too often we seem to have had ideas and forgotten them until others have developed them." How truly he spoke, and how dimly is any change in attitude to be seen in Great Britain. Let us, therefore, see that every encouragement is given to those who are ready to break with tradition and carry us to new heights of achievement.

CERAMIC BACKING FOR TUBE JOINTS

BELA RONAY

THE AUTHOR

Head of Engineering Department, Metal and Thermit Corporation 1915-1931, concerned with the development of procedures, apparatus and test methods in connection with Thermit welding. Appointed in 1931 to establish a Welding Laboratory at the U. S. Naval Engineering Experiment Station, Annapolis, Md., with a mission concerning welding problems pertaining to the fabrication of propulsion equipment. Since 1949 Superintendent of the Welding and Electrical Laboratory. Frequent contributor to the Journals of the A.S.N.E. and A.W.S. Member A.W.S., A.S.M., A.S.T.M. and A.S.N.E.

The term "Welding Procedure" covers the factors which are to be considered in the controlled production of welds. In pipe welding the outstanding factors are joint design, welding technique and filler metal. This paper considers primarily joint design by the reason that root preparation, which includes the backing material, is directly related to the development of ceramic backing for tube welds.

Piping intended for high pressure, high temperature service is a complex, highly stressed component of a power plant. The welded joints contained in a pipe system should, therefore, represent notch free continuity. Where auxiliary equipment is designed to operate on superheated steam, as on some Naval vessels now under construction, the feed pipes are small, many less than 1½" I.P.S. The use of metal backing rings, particularly the type preferred by the Naval Service, would render each point of application a throttling orifice, thereby reducing the effectiveness of the feed lines. On the vessels now under construction this problem has been solved by the use of socket type fittings, thus eliminating butt joints and the use of backing rings. However, it is conceived that in the event of an intensified building program, a shortage of socket type fittings may make it unavoidable to resort to the use of butt joints.

In order to obtain welds suitable for high temperature, high pressure service, a large variety of butt joint preparations were considered and tested. Those accepted by the various code authorities

V. BUTT JOINT
WELDED ON MACHINED TYPE BACKING RING
(INDUSTRY)

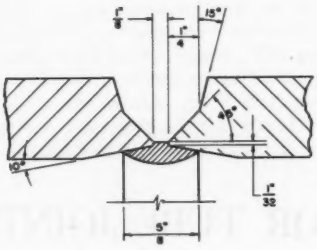
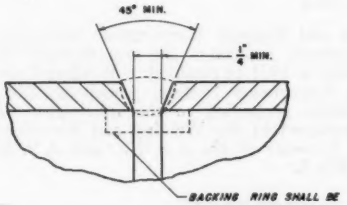


Fig. 1

V. BUTT JOINT
WELDED ON REMOVABLE BACKING RING
(NAVY DEPARTMENT)



NOTE: THIS JOINT USED FOR WELDING FLANGE TO PIPE.

Fig. 2

FILLET WELDED SOCKET
(NAVY DEPARTMENT)

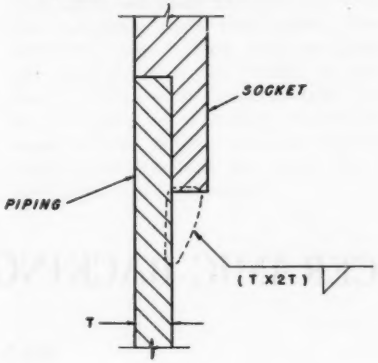


Fig. 3

V. BUTT JOINT
WELDED ON PLAIN TYPE BACKING RING

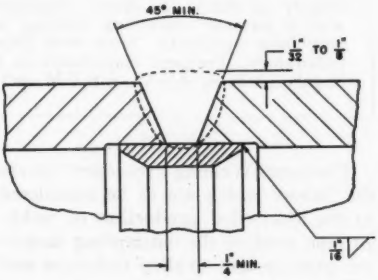


Fig. 4

of industry and the Bureau of Ships of the Navy Department are shown in Fig. (1), (2), (3) and (4) respectively.

The butt joint used for high pressure lines installed in Naval vessels and other installations built under the cognizance of the Bureau of Ships is shown on Fig (4). The keynote of this design is simplicity, aiming for the most economical method of preparation of the beveled edges and employing a backing ring which is also basic as regards simplicity of its geometry. The above design further specifies boring out the tube ends to match diameters so that the backing ring may fit snugly against the entire periphery of both bores. This requirement adds considerably to the cost of the preparation in that tolerance in boring out tube ends cannot exceed .005" if the desired close fitting between tube ends and the ring is to be obtained. The reason for the close tolerance is readily seen when a joint preparation is regarded as an open top mold consisting

of three sides. Two sides of the weld are the beveled edges of the tubes to be joined and the third is the backing under the root of the joint. Since arc welding, employed almost exclusively in the fabrication of high pressure piping is a progressive casting process, it is evident that the mold must be tight against the liquid metal deposited in the course of the development of the first pass. The metal deposited by arc welding is in the superheated state and, therefore, very fluid. A gap at the root of the weld measuring only a few thousandths of an inch in width permits leakage. The steel, finding its way in the narrow gap, is chilled immediately upon entering. The temperature gradient developed by the sudden chilling induces a corresponding stress development, which often results in incipient cracks oriented upward into the weld metal. The significance of these cracks which may vary in size from microscopic to that visible to the naked eye, as stress raisers is obvious. The requirement to bore out the tube ends to provide close faying for the backing ring is undesirable not only because it is an additional, expensive machining operation, but also as it is necessary to follow through, to assure that the bore diameters of each joint match within the specified tolerance. The development of ceramic backing during World War II was primarily influenced by the acute shortage of personnel qualified to do the work of the inspection and follow up. However, by the time the development was completed, the war construction program was well established and it did not appear to be advisable to introduce a new procedure that would have interfered with the established production schedules. Thus, the application of ceramic backing was held in abeyance pending a suitable opportunity. This offered itself in connection with the installation at the Naval Engineering Experiment Station in Annapolis, Maryland, of a test cell to evaluate various types of steels as materials for piping in steam lines intended for service at 1050°F at 2000 p.s.i. The line carrying the superheated steam into the test cell was 4/6 Cr-½ Mo steel, schedule 160, 1½″ IPS tubing. A total of 80 joints were required for the completion of this line from the superheater to the test assembly. It was considered that this was an opportunity to install and evaluate ceramic backing as regards its suitability and reliability in high pressure, high temperature steam lines subject to repeated thermal shock and the corresponding transient thermal and dynamic stresses. The design of the joints for use with ceramic backing, the volume and contour of the ceramic material as applied in these joints are shown in Fig. (5).

The principles employed in developing this design were based on two considerations; one pertains to the joint design, the other the selection of the backing material. At the beginning of the development work a high temperature refractory material was employed to resist arc impingement. However, early experience showed that arc impingement must be avoided to prevent contamination of the deposited metal and that this objective must be attained through modification of the joint design.

The joints shown in Fig. (5) present the final design developed toward the attainment of the above objective. The distinctive feature of this design is that it is not symmetrical for wall thicknesses greater than ⅛″. One side is beveled at 45°, the other at 15°, which is faired into the 3/16″ radius at the root. The root is formed by two tips which are produced by counterboring, thus raising the root edges 1/16″ above the bottom of the joint. The root space between these edges is 3/32″. The ceramic backing is shown to be at least ⅜″ thick and ⅜″ wide and it is also counterbored, forming an annular space under the root edges. These design

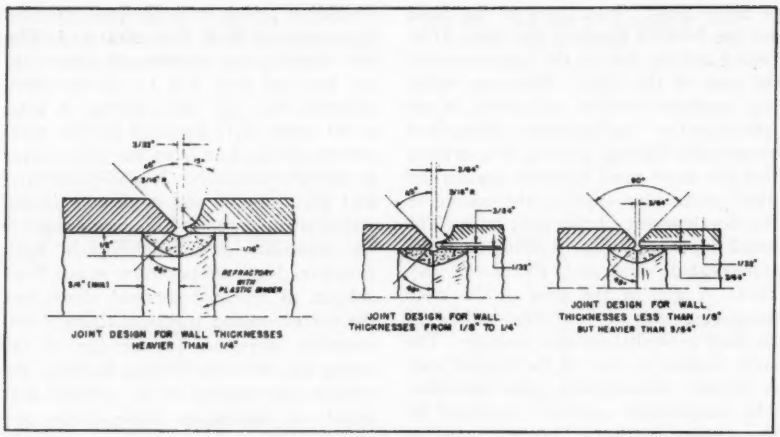

JOINT DESIGN FOR WALL THICKNESSES HEAVIER THAN 1/4"
JOINT DESIGN FOR WALL THICKNESSES FROM 1/8" TO 1/4"
JOINT DESIGN FOR WALL THICKNESSES LESS THAN 1/8" BUT HEAVIER THAN 3/64"

FIG. 5

features were found to satisfy the principle applied in their development by:

(a) Providing base metal at the root of the weld to prevent the arc from impinging directly upon the ceramic backing.

(b) Proportioning the protruding portions of the bore at the root to assure that it is melted down by the heat input of the applicable small electrodes.

(c) Providing amplitude for the manipulation of the electrode by machining a "J" contour in one of the tube ends.

(d) Providing mass by the 45° bevel to absorb the heat of the arc when occasionally the electrode must be whipped to prevent undue widening of the root gap.

(e) Counterboring the ceramic backing to provide space for a shallow head and thus further assure complete remelting of the root edges.

(f) Providing a $\frac{3}{64}$" overhang of the ceramic backing whereby the root edges become separated by a total of $\frac{3}{32}$". The presence of this gap serves as a safeguard in remelting the root edges and provides for complete fusion.

The details of preparing and applying the ceramic backing and of the welding technique applicable in depositing the first pass of the weld (deposition of the subsequent passes is done in the conventional manner) are given in the following:

1. The backing material is sharp sand procured in accordance with Bureau of Ordnance Specification 50-S-2, No. 20.

2. The preferred binder is cellulose acetate applied from commercially available dispensing tubes. This material is a thermoplastic. Its setting time in air is approximately ½ hour. When it is desired to reduce the setting up time of the mold by torch heating, care must be used not to impinge the flame on the exposed portion of the backing material. Heating the tube ends to 300° F. reduces the setting up time to 15 minutes.

3. Application of the ceramic backing material. In preparing this nonmetallic backing material, the sand and the binder are mixed into a putty-like consistency. The ratio of sand to binder is approximately 5 to 1. This mixture will adhere readily to the bore of the tubes to be joined. In the

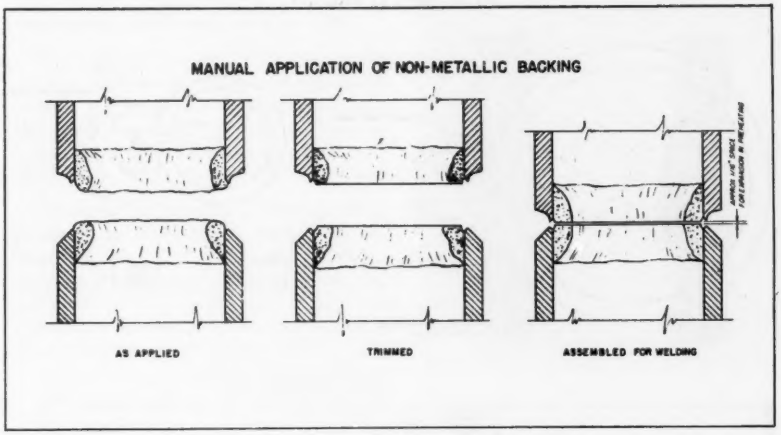


FIG. 6

TRIMMING JIG AND SLEEVE FOR STRAIGHT TUBING

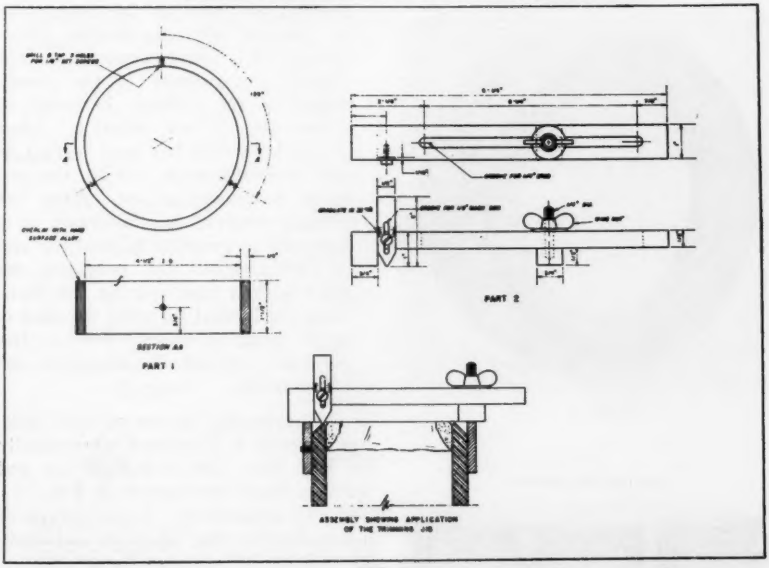


FIG. 7

NON-METALLIC BACKING RINGS USED
WITH PART 2, FIG. (7)

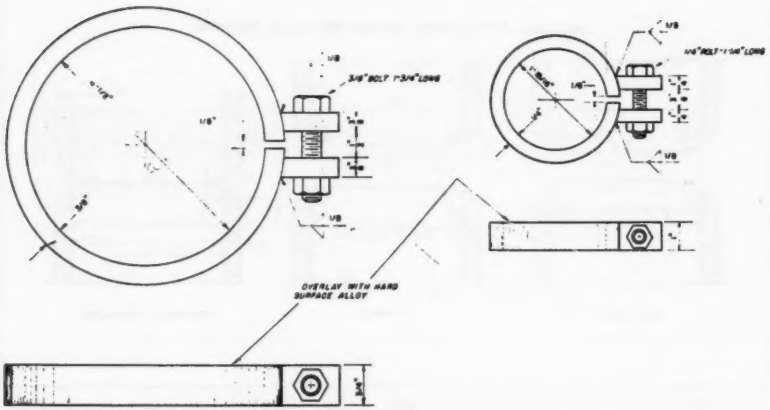


FIG. 8

CERAMIC BACKING PREPARED
FOR ASSEMBLING

FIG. 9

ROOT BEND TEST SPECIMENS

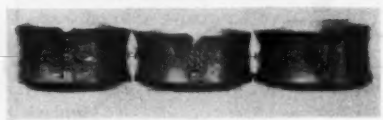


FIG. 10

event the mixture does not adhere readily, the bore of the tubes may be smeared with the binder. Occasionally, it is found necessary to vary slightly the quantity of the constituents of the mixture in order to obtain the desired adhesion. After the backing ring has been formed in each tube end to be joined, the material is allowed to set. When the backing material has hardened, it is faced-off to protrude beyond the end of each member thus providing the joint with a root spacing. A trimming jig is used for this; the sand is faced using a coarse file; a tri-cornered scraper is employed for undercutting.

The application of non-metallic backing material is illustrated schematically on Fig. (6). The trimming jig and leveling sleeve are shown on Fig. (7) and (8) respectively. A photograph of a non-metallic ring undercut and ready for welding is shown on Fig (9).

A photograph of bend specimens taken from a tube joint welded over a non-

metallic backing ring are shown on Fig. (10). Macro-etched transverse sections are presented on Fig. (11).

Considering the fact that the curing periods mentioned above may be undesirable in production work, a mold was designed for prefabrication of backing rings for standard pipe sizes up to 1½" IPS. This mold is shown on Fig. (12).

Training of Operators. The operators assigned to learn the technique of *depositing the first pass over ceramic backing* should have had previous experience in pipe welding. Before the applicable technique is demonstrated to them, they are instructed as follows:

(1) The arc must be struck on the 45° bevel and slowly advanced into the root.

(2) Hold the arc long enough to develop a hole slightly larger than the diameter of the electrode used.

(3) Start advancing when the hole is developed, at a rate which permits maintaining the hole at the same diameter. Slow down if the hole diameter appears to diminish. If the hole increases beyond the desired size, whip the electrode against the 45° bevel. When the pool begins to lose fluidity, redirect the electrode there, close up the enlarged hole and resume progression.

MACRO ETCHED WELD SECTIONS

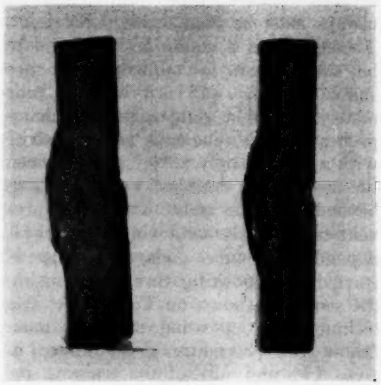


FIG. 11

MOLD FOR CERAMIC BACKING

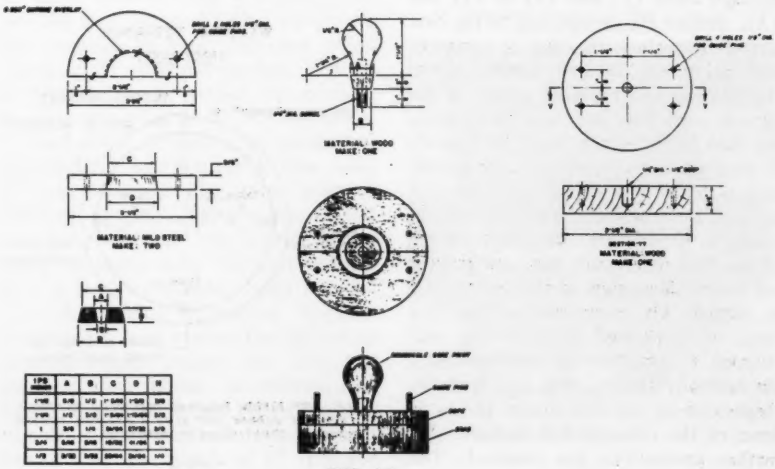


FIG. 12

Welding Technique. In setting up ceramic backed tube joints suitable clamps must be used to align the joint. The details of a clamp design found to be satisfactory for this purpose are shown on Fig. (13). When the tube material is of a composition requiring preheating, the tube ends are assembled with approximately a 1/16" gap between the faces of the sand backing protruding beyond the tube ends. This is to prevent crushing the sand when the preheat expands the tube ends. Welding is started by depositing three tacks using the sequence shown on Fig. (14). The technique of depositing the tacks must follow the procedure given above in steps (1) and (2) of the training instructions. These tacks are from 1/4" to 3/8" long. The tacks are cleaned free of slag by use of a scratch tool without pecking. When cleaned of slag, the tacks are closely examined for cracks or fissures. If any are found, they are removed by grinding using a lightweight, high-speed air or electric grinder carrying a suitable size burr as the grinding tool. Next, for horizontal fixed joints, welding is started at the bottom and performed as given in (1), (2) and (3) of the above instructions, welding through tacks (1) and (2) or (1) and (3). Before the second half of the first pass is deposited, the slag is removed, still using the scratch method, from the starting and finishing points of the already completed half and these areas are then inspected for cracks or fissures. If none are found, welding of the second half is performed in the same manner as used for depositing the first half. If cracks or fissures are found in the crater of the first increment, they are ground out before deposition of the second half is started. On completion of the first pass, it is cleaned free of slag and chipped to improve its contour using the normally applied tools and methods. Deposition of the subsequent passes is done in the conventional manner. No further precautions are required. The

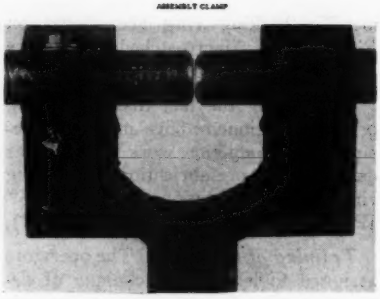


FIG. 13

above given procedure applies also to welding in the vertical. Welding in the horizontal rotated position is also practical, after the three tacks have been completed with the assembly firmly held by a clamp.

Removal of the Backing Material. The heat of welding volatilizes the binder contained in the outer portion of the backing ring. This renders it very brittle. The vigorous pounding in dressing the completed first and subsequent passes of the weld shatters the brittle backing material which returns to its original form, namely, sand particles.

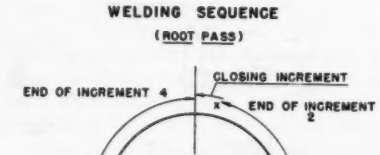

WELDING SEQUENCE
(ROOT PASS)
CLOSING INCREMENT
END OF INCREMENT 4
END OF INCREMENT 2
TACK 3
TACK 2
END OF INCREMENT 3
END OF INCREMENT 1
TACK 1
START OF FIRST & THIRD INCREMENT
NOTE:
(X) STOP BEFORE REACHING TACK WELD TO PERMIT VENTING. SCRAPE OUT SLAG & EXAMINE CRATER BEFORE STARTING NEXT INCREMENT.

FIG. 14

These can be removed by shaking or flushing with water or may be blown out by air. No gobs of molding material remain adhering to the root of the weld in that complete separation of backing and weld metal occurs during the chipping and cleaning of the first and subsequent passes. Occasionally, over small areas the sand vitrifies and adheres to the bottom of the weld. Few particles are fused on as a vitrified enamel. Such vitrified adhesions, measuring about ⅛" in length and width, were found on welds removed from the above given steam line. Since this line has been subjected to several hundred thermal shocks of a very serious order, it is evident that those particles do not become dislodged and therefore, do not constitute a threat to valve operation or fouling of turbine blades. In the operation of the above steam line, which involved hundreds of openings and closings of valves, at no time was trouble experienced and on no occasion was the operation of the valves impaired.

Further Applications. The use of ceramic backing at the Station has been applied in the construction of two high pressure, high temperature steam lines. In these systems both 4/6 Cr-½ Mo and 2¼ Cr-1 Mo steel tubing were used. The ceramic backing was used in all joints of 2" IPS and smaller. A total of 150 joints were welded over ceramic backing. For tubes of 4" IPS and larger it was found necessary to strengthen the backing by mixing in the sand of approximately 25% (by volume) shredded asbestos. The presence of this material, with the heat of the stress relief treatment fully disintegrates and does in no way interfere with removal after the weld is completed. Ceramic backing has been used at the Station in welding copper, copper base alloy and stainless steel tubing. In welding 4/6 Cr-½ Mo tubing it has been found advisable to post heat all joints regardless of size. For joints of 3" IPS and over the induction method was used for preheating, maintaining the interpass temperature and the post heat treatment. Joints 2½" IPS and smaller were preheated by a welding torch, which was also used for maintaining the interpass temperature. The post heat treatment for these joints was performed using charcoal furnaces. The design of those furnaces for horizontal and vertical joints is shown on Fig. (15) and (16) respectively. Air blown through the tuyeres is admitted through a regulating valve from a 125 p.s.i. supply line. The valve reduces the pressure to the operating range of 6 to 12 p.s.i. Temperature regulation is by means of a thermo couple welded to the joint. The thermo couple leads are protected by a small steel tube which rests on the joint. Heat regulation is obtained by controlling the volume of air admitted to the tuyeres. This can be done manually, by reference to a potentiometer or a resistance type temperature indicator. Automatic regulation can be applied by having an automatic temperature controller actuate a solenoid valve installed beyond the reducing valve.

CHARCOAL FURNACE FOR TUBE JOINTS IN HORIZONTAL POSITION

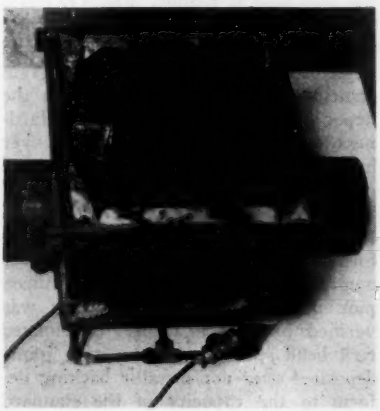


FIG. 15

CHARCOAL FURNACE FOR TUBE JOINTS IN THE VERTICAL POSITION

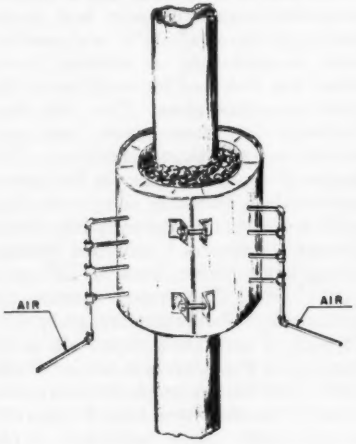
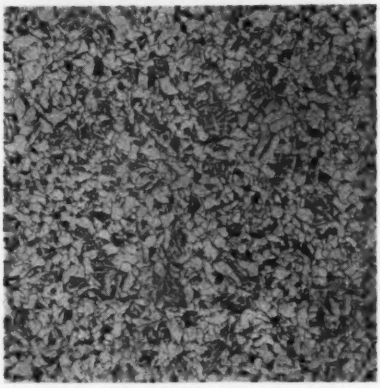


FIG. 16

MICROGRAPH OF WELD METAL, REFINED, ROOT PASS (X100)



2
FIG. 17

The design of the charcoal furnaces, the joint used in connection with non-metallic backing material and the compounding of the backing materials are proprietary.

Examination of the Weld Root. Metallurgical examination of the weld root, produced over non-metallic backing, reveals that the grain structure in the root pass is refined. Fig. (17) is a photomicrograph of the refined grain structure obtained in the root pass and Fig. (18) shows the unrefined grain structure of the weld metal from the upper half of a ⅜" thick joint. Hardness exploration of welds made over non-metallic backing indicates normal conditions for the root zone as evident from the hardness survey shown on Fig. (19). Spectroqualitative analysis performed for sections of welds made over non-metallic backing indicates no silicon pick up for the root zone; this was verified by wet analysis. Untrimmed root bend specimens taken from joints deposited over non-metallic backing deform to the capacity of the standard Navy bending jig. Most Codes require X-ray examination of the joints in pressure piping systems although this method seldom reveals the presence of shallow root cracks, nor can these be detected reliably by the ultrasonic method in the presence of metal backing rings.

MICROGRAPH OF WELD METAL, UNREFINED, TOP PASS (X100)

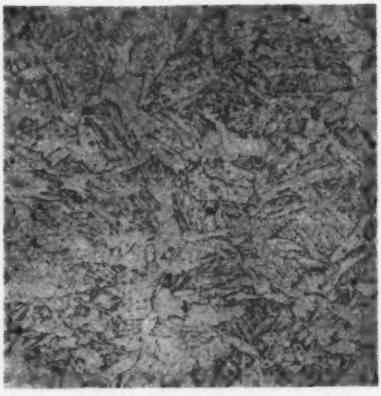


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FIG. 18

HARDNESS SURVEY (BRINELL)

Weldment	Unaffected Base Metal	Heat Affected Base Metal	Weld Metal	
			Root Area	Body
Ceramic backing	121 to 135 127 avg. Tubing	222 to 234 228 avg.	245 to 255 250 avg.	234 to 250 240 avg.
Metallic backing	169 to 180 172 avg. Plate stock	205 to 240 222 avg.	250 to 265 255 avg.	234 to 260 250 avg.

FIG. 19.

Welds produced over non-metallic backing rings can be given fast 100% nondestructive tests by the magnetic analysis or ultrasonic methods with the assurance that unsound root conditions, if present, would be detected.

Summary. Power piping is regarded as the most critically stressed component of a steam power plant. While most of the other portions of a steam power plant are shop fabricated under the most applicable conditions and by the use of automatic welding devices, much of the piping is welded in the field. Erection of piping in the field handicaps the proper alignment of metal backing rings. Experience shows that the greatest difficulty in pipe welding, using metal backing rings, is the development of sound root conditions. The use of non-metallic backing in the joints defined in this paper offers a solution to the most objectionable feature of pipe welding. Non-metallic backing offers:

(a) Elimination of undesirable throttling in small lines.

(b) Enables the consistent production of joints whose root zones are metallurgically sound.

(c) Eliminates corrosion dangers by removing the sediment catching ring obstacle.

(d) Better economy than metal rings.

Non-metallic backing as presented here offers an important gain toward the consistent production of sound joints in power piping.

A 1000-KW GAS TURBINE-ALTERNATOR SET FOR THE ADMIRALTY

ACKNOWLEDGMENT

This is a condensed version of an article appearing in the January 1952 issue of "The Shipbuilder and Marine Engine-Builder."

INTRODUCTION

From time to time in the recent past, brief references have been made to gas-turbine developments undertaken by Messrs. W. H. Allen, Sons & Co., Ltd., of Bedford, with the sponsorship of the Admiralty.

To give definition to the project, the Admiralty, in 1948, placed with Messrs. Allen a development contract which involved the construction of a 1000-kw. gas-turbine/alternator set, suitable for auxiliary service in H.M. ships, and, during the past three years or so, the firm have devoted much careful thought and technical skill to the design and construction of the gas-turbine prime mover, which has now been under test since the early part of 1951. It is a tribute to the foresight and technical competence of the staff of Messrs. Allen, and of the Admiralty officers who have collaborated with them, that such mechanical "teething troubles" as were experienced were of an altogether minor character. In the first series of tests, it is significant that the unit was operated at full speed, under full-load and even overload conditions, without difficulty.

The further program of trials now in train has been planned to provide data in regard to the general performance and governing of the unit, and these will be followed by rigorous endurance tests.

DEVELOPMENT OF THE DESIGN

It was laid down in the Admiralty specification that the set should have a maximum continuous rating of 1000 kw. and that it should be capable of sustaining an overload of 20 percent for a period of 10 minutes. Moreover, the set was to be suitable for operation at all loads (up to overload) under temperate (60 deg. F.) or tropical (100 deg. F.) conditions, and capable of operating satisfactorily in parallel with steam-turbine/alternator sets. The governing requirements stipulated that the change of speed corresponding to a 50 percent variation in load should not exceed 2½ percent, while the set was to be capable of accepting or shedding 100 percent load, without the assistance of the emergency gear.

It was further envisaged that the fuel would be Diesel oil (Admiralty Fuel B.310), with a maximum fuel consump-

tion of 1.27 lb. per kw.-hr. under tropical conditions, in the range 60 to 100 percent of full power.

The total head-pressure at the compressor intake was to be 14.1 lb. per sq. in. (abs.) and at the power-turbine outlet 15.1 lb. per sq. in. (abs.)—values which allow for substantial losses in the inlet and exhaust trunking.

The engine was to be entirely self-contained and was to be as compact as possible, consistent with reasonable accessibility. To permit its installation in a normal between decks, a maximum height of 7 ft. was specified and it was laid down that every reasonable opportunity should be taken to reduce the weight of the set without, of course, impairing reliability.

In regard to shock loading, it was specified that the set should be designed and mounted to sustain high acceleration in both vertical and horizontal directions, *viz.*, 40 *g* upwards, 25 *g* downwards and 15 *g* transversely.

Finally, an endurance of 100,000 hours, comprising 65,000 hours at 80 percent power under temperate conditions, and 33,000 hours at 80 percent power and 2000 hours at full power, under tropical conditions, was to be aimed at.

Other characteristics of the design are summarized in the accompanying table. It will be observed that the thermal efficiency and specific fuel consumption are not comparable with those of a modern Diesel engine, but this limitation was accepted as a reasonable measure at the present stage of gas-turbine development, especially having regard to the questions of reliability and long operating life.

After a careful examination of the conflicting requirements of low weight and space on the one hand, with those of reasonably good efficiency on the other, Messrs. Allen decided to adopt

BASIC DESIGN DATA OF THE ALLEN GAS TURBINE.

B.H.P. continuous maximum rating (C.M.R.) at power-turbine coupling, including fouling margin	1,512
Estimated fuel consumption, at C.M.R. lb. per B.H.P.-hr.	0.745
Estimated thermal efficiency at power-turbine coupling, at C.M.R., percent	19.75
Mass flow at C.M.R., lb.-sec.	37
Maximum gas temperatures, deg. C.:	
Under temperate conditions	650
Under tropical conditions	700
R.P.M.:	
Compressor	8,000
Power turbine	6,750
Alternator	1,500
Estimated adiabatic efficiencies, percent:	
Compressor	84
Compressor turbine	85
Power turbine	84
No. of stages:	
Compressor	13
Compressor turbine	2
Power turbine	1
Combustion chambers:	
Number	8
Type	Straight-through
Burners	Lucas Simplex
Heat exchanger:	
Thermal ratio, percent	70
Number of passes:	
Hot air	1
Cold air	2

Note:—The stated output is that obtained with the abnormal inlet and exhaust losses specified. Without these, the C.M.R. output under temperate conditions would be 1250 kw., the corresponding thermal efficiency 24 percent, and the specific fuel consumption 0.625 lb. per B.H.P.-hr.

a comparatively simple open-cycle set, incorporating an axial-flow compressor (compression ratio 4¼:1) driven by a two-stage turbine. Other components were to comprise an annular two-pass cross-flow heat-exchanger; a multi-chamber combustion system, disposed symmetrically round the engine; and a separate, single-stage power turbine, the output from which was to be transmitted through Allen-Stoëchicht epicyclic gearing to the alternator.

The photograph in Fig. 1, depicts the set as erected for testing in Messrs. Allen's works at Bedford. In this photograph, the lagged outer covers are absent, so that the compressor, turbines, air pipes, heat-exchanger, combustion chambers

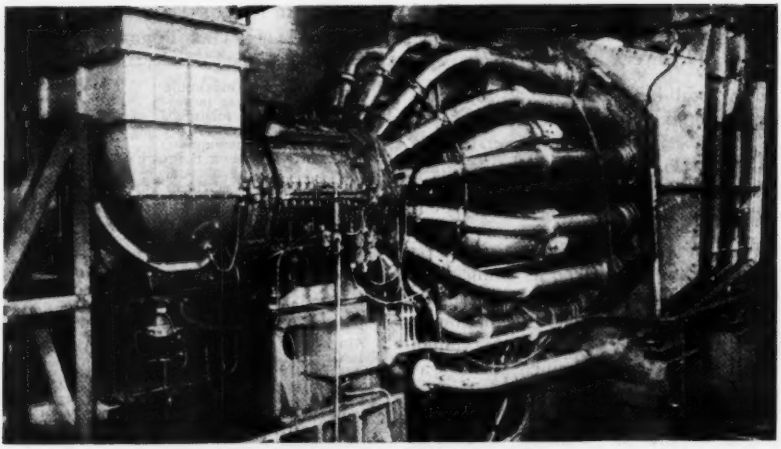

Fig. 1.—Allen 1,000-kW. Gas Turbine.

and other features are exposed. The air-intake trunk is at the left, while the exhaust outlets are arranged at each side of the heat-exchanger.

The height of the set is within the required 7 ft., and the dimensions, in plan, are 16 ft. by 8 ft. 6 in. The total weight of the gas turbine, including the heat-exchanger, but excluding the alternator, is 8½ tons.

It may be noted that the unit is without a base plate, three-point support being effected by the independent mounting of the compressor. The supports at the sides of the heat-exchanger are flexible, to accommodate thermal expansion and contraction; while, in view of the fact that the set is intended especially for installation in naval vessels, resilient rubber components are incorporated in the mountings to minimize the effects of shock-loading due to underwater explosions.

CONSTRUCTIONAL FEATURES

The mechanical design of the gas turbine is based on the component-assembly principle, so that each assembly may be removed from the machine independently of the others. At the same time, careful attention has been paid to the question of accessibility to facilitate inspection and maintenance.

Compressor.—The compressor is of the axial-flow multi-stage type, the rotor being of special built-up construction, designed to reduce the moment of inertia of this component to the smallest possible value, and thereby assisting the speed governor during sudden large fluctuations in load.

The inlet end of the shaft is manufactured from 1 percent chrome/molybdenum steel, while the outlet end is in Nitralloy steel, hardened in way of the bearing journals. The rotor wheels, too, are of 1 percent chrome/molybdenum steel, the individual discs being secured to each other by means of dowel pins on the faces of the bosses and through which the torque is transmitted.

The rotor-disc assembly and the shaft ends are clamped together to form a

single assembly by means of a special steel bolt which passes axially through the centrally bolted discs. Due allowance has been made in the design of this bolt to enable it to withstand the thermal and other stresses which may occur during running.

Concentricity is maintained between the compressor-disc assembly and the two stub shafts, under all conditions of speed and temperature, since they are butted together on the faces by means of Hirth couplings.

Each of the 13 stages of the compressor rotor has 76 blades, manufactured from 13 percent chrome stainless iron. The blades, which are of constant aerofoil section and of a height appropriate to the particular stage, are machined integral with their roots and are wired together in groups of 10 to facilitate assembly. They are lightly located between the rims of adjacent wheels by a groove machined in the roots and which engages a corresponding register on the discs.

The assembly of the discs and blades was carried out with the axis of the rotor vertical. Incidentally, the blade profiles have been machined by Centrax, Ltd.

The stator blades, also of aerofoil section, are in Monel rolled strip, cast into combined roots and spacers, and secured in grooves in the casing.

The casing itself is a steel casting, divided at the horizontal center-line. Double-skin construction of the casing was adopted to provide sufficient space for an adequate blow-off of air, but this feature has since been found unnecessary.

Heat-exchanger.—The heat-exchanger is of the tubular, cross-flow, recuperative type, with a single pass on the hot exhaust-gas side and two passes on the cold inlet-air side. It comprises eight segments, each containing just over 2000 tubes in Yorcalnic, manufactured by the Yorkshire Copper Works, Ltd., of Leeds. The tubes, which are 5/16 in. outside diameter and 0.02 in. in thickness, are secured to mild-steel tube plates by ferrules, expanded into the plates by means of a hydraulically operated riveting gun, developed and supplied by Aviation Developments, Ltd., of London.

The method is shown by the drawing in Fig. 2. The ferrules are threaded on a mandrel, which is then loaded into the gun. The first ferrule and the mandrel are inserted into the tube and the operation of the gun draws the mandrel through the ferrule, expanding it and the tube into the plate. After being expanded, the inside diameter of the ferrule is, of course, the same as that of the tube bore. The method has been found entirely satisfactory and is, moreover, extremely rapid.

The shell of the heat-exchanger is fabricated in aluminized mild steel.

Combustion Chambers. — The multichamber combustion system comprises eight compartments, disposed symmetrically about the axial center-line of the turbine shaft. The combustion

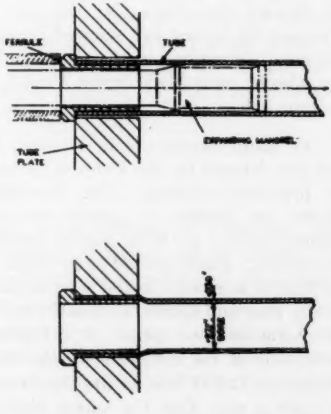

Fig. 2.—Method of Securing Tubes in Tube Plates.

chambers were designed and manufactured by Messrs. Joseph Lucas (Gas Turbines), Ltd., of Birmingham. The inner flame-tubes are in Nimonic 75—a nickel/chrome alloy—and are cooled by the secondary air. The outer air casing, which is of aluminized mild-steel sheet, is fitted with two bellows expansion pieces which accommodate differential expansion between the turbine casing and the heat-exchanger.

Each end of each combustion chamber is secured by a special quick-release joint.

Compressor Turbine.—The compressor turbine is of the axial-flow type and comprises two stages.

The two G18B steel rotor wheels and the stub shafts are bolted together by means of a pre-stressed manganese/molybdenum bolt, which passes through the centrally bored wheels, and which is specially designed to cater for the large expansion which occurs in the wheels themselves. Hirth couplings are again employed to locate the wheels and the Nitralloy-steel stub shaft, which is hardened in way of the bearing journals.

The rotor blades, manufactured on the plunge grinding process, patented by the Bristol Aeroplane Co., Ltd., are in Nimonic 80.A. and are secured in axial "fir-tree" serrations in the periphery of the wheels, each blade being fixed by a locking key.

The stator blades are in Nimonic 80, and are formed by the lost-wax process of precision casting. The first-stage blades are riveted in groups to segmental strips, to form easily handled assemblies. Each second-stage blade is secured in a groove in the intermediate-casing ring and located circumferentially by means of two pegs. A cylindrical projection at the inner end of the blade engages a radial hole in the diaphragm, in such a way that the stator blade is free to expand radially towards the center of the diaphragm, while the diaphragm can expand radially outwards.

The diaphragm is protected by heat shields, designed to prevent distortion due to the temperature gradient.

The casing consists of inner and outer members, designed to minimize thermal stresses due to expansion and to allow all parts to expand freely and yet remain concentric. A center casing ring of heat-resisting material is located in the main casing by radial keys, the arrangement being such that it is free to expand radially at all points on its circumference.

Inner segmented shroud rings of H.R. Crown Max steel are arranged to expand circumferentially in grooves in this casing ring. This arrangement maintains the blade-tip clearances at all loads, thus improving the efficiency and also allowing the machine to be started and shut down rapidly, without risk. Cooling air from the compressor passes round the inner casing and through passages in the center casing ring before joining the main gas stream.

The coupled compressor and driving-turbine shafts are supported in three bearings. To allow for any misalignment of the shafts, they are connected by a quill shaft, which forms an extension of the turbine shaft, and which is located in the bore of the compressor shaft. The driving torque is, however, transmitted through a normal gear tooth muff coupling.

Power Turbine.—The power turbine—a single-stage axial-flow machine—is mechanically independent of the compressor turbine.

The materials and general construction of this turbine are similar to those of the compressor turbine, with the exception that the rotor wheel is of H.40 ferritic steel, manufactured by Messrs. William Jessop & Sons, Ltd., of Sheffield.

The bearing is connected radially to the outer main-turbine casing by four fabricated struts, enclosed in streamlined aerofoils, which are themselves integral with the mild-steel exhaust-diffuser ducting assembly of the power turbine.

Turbine Cooling Systems.—Great attention has been paid to the design of the cooling arrangements of the rotors and casings, the several systems being planned so that air from the compressor delivery is conveyed, *via* passages in the turbine casings, to both sides of the turbine-rotor discs, before finally joining the main gas stream.

Bearings, Glands, etc.—All the main bearings are of the sleeve type, the design generally following well-established steam-turbine practice. The bearings are of steel, lined with white-metal, with the exception that those exposed to the higher temperatures are lined with lead-bronze. Lubrication and cooling of the bearings are effected by oil at a pressure of approximately 10 lb. per sq. in.

Ball and roller bearings are incorporated in the auxiliary drives, and the thrust bearings are of the Michell type.

The journal bearings are fitted with thermocouples, and the thrust bearings with hydraulic wear gauges.

The casing glands of the compressor and turbine, as well as the interstage glands, are of the labyrinth type, consisting of stationary stainless-iron fins, in association with stepped shaft-journals.

Flexible Couplings.—The turbines are connected to their respective shafts by continuously lubricated internal tooth-type couplings, in which oil is fed, by centrifugal action, through internal passages to each tooth engagement.

GEARING

Speed reduction between the power turbine and the alternator is effected by Allen-Stoëchicht double-helical epicyclic gearing, which achieves the maximum saving in weight and space.

Designed on the well-known Stoëchicht principle (which ensures equal sharing of the load not only by the planet wheels, but also by the helices), the gearing is capable of transmitting 1800 hp. continuously; its geometrical characteristics are such that the speed of the output (alternator) shaft is 1500 rpm., when the power turbine rotates at 6750 rpm. High speed shaft bearings are eliminated from the gear unit, the sun wheel (which is supported between the three planet wheels) being connected to the power turbine by means of a flexible coupling of the double-helical-tooth type.

ALTERNATOR

The alternator, also manufactured by Messrs. W. H. Allen, Sons & Co., Ltd., is of the open self-ventilated, rotating-field, salient-pole type, the maximum continuous rating being 1000 kw. at 0.8 power factor. The machine is designed to generate 50-cycle, three-phase alternating current at a tension of 400/430 volts, when rotating at 1500 rpm., and is capable of sustaining an overload of 20 percent for a period of 10 minutes.

The stator windings are of high-conductivity copper, insulated with moulded Micanite, and are held in position by wedges of synthetic-resin bonded fabric.

The rotor poles are secured to a steel shaft, which is carried in a single split-sleeve bearing of pedestal type, and arranged for rigid coupling to the gear-wheel shaft. Pressure lubrication of the bearing is effected by oil from the turbine lubricating system.

A carbon-pile voltage regulator is connected in the exciter-field circuit, and, to obtain rapid voltage response, a permanent-magnet pilot exciter, belt-driven from the main exciter, is employed, the arrangement avoiding the need for a small commutator and brush gear. The pilot exciter comprises a four-pole permanent-magnet rotor in a normal stator frame, and the output from this unit supplies the field of the main exciter *via* a metal-oxide rectifier located in the main exciter at the bottom of the commutator end bracket.

The exciter is of the two-bearing type, flexibly coupled to the rotor shaft, and is provided with a shunt field regulator.

LUBRICATION

The lubricating system follows closely that usually employed in steam-turbine practice. Of the two separate, valveless gear-type oil pumps, one delivers oil at a pressure of about 120 lb. per sq. in. (gauge) to the governor-oil system; the other, which serves the bearing and gear-teeth lubricating circuits, delivers at a pressure of about 45 lb. per sq. in. (gauge).

The pumps, which are arranged in tandem, may be driven either by an electric motor (as in starting), or by the turbine shaft, through gearing, during normal running. Provision is made whereby the drive may be automatically transferred from the motor to the turbine when the speed of the latter has attained a value which is sufficient to maintain the pressure in the oil system.

Oil for the governor pump is taken from the lubricating system, so that the lubricant for both systems passes through a filter and cooler.

FUEL SYSTEM

The fuel-oil system is of simple design and incorporates Lucas Simplex burners. The quantity of fuel delivered to the combustion chambers is regulated by a throttle valve in the pipe which supplies oil to the burners, the valve opening being controlled by the speed governor, through a high-pressure oil relay. A hand-controlled throttle valve is provided for use in starting the plant.

The fuel pump is of the Lucas B type, and is driven through gearing from the compressor shaft.

An emergency valve in the fuel system functions automatically to interrupt the supply, in the event of turbine over-speeding or failure of the lubricating-oil pressure. The valve may also be closed by the manual operation of suitable trips on the turbine and on the control panel.

Four of the eight interconnectors between the combustion chambers are fitted with a torch igniter assembly, each comprising a thermocouple, a plug and the torch itself. Complete certainty of starting is ensured, as ignition in each chamber is effected directly from a torch. As a double safeguard against the failure of one or more torches, the interconnectors ensure satisfactory ignition in all the chambers.

SPEED CONTROL

The speed-control governor is of the centrifugal type and is driven from the power-turbine shaft.

To assist the governor during sudden changes of load, a small flywheel, housed in the reduction-gear casing, is fitted to the high-speed shaft. As remarked earlier, the rotating assembly of the compressor has been specially designed to ensure that its moment of inertia is reduced to the minimum.

A handwheel on the governor allows the speed of the power turbine to be adjusted, at no-load, to within $\pm$ 5 percent of the rated speed. A small electric motor incorporated in the governor gear allows this speed adjustment to be effected from both the switchboard and the control panel.

In addition to the main governor, emergency over-speed trip governors, of the shock-proof unbalanced-ring type, are provided. Such units are fitted to both the compressor and the power-turbine shafts, and they are arranged to operate an emergency shut-off valve in the fuel system. They function by destroying the pressure in the oil relay, in the event of the rated speed being exceeded by a predetermined amount.

Hand trip-cocks are provided on the machine and on the control panel.

STARTING

The starting procedure is briefly as follows:

The compressor is "run up" by an electric motor to a speed of approximately 1500 rpm. (This operation requires about 16 hp.)

The torch igniters are then lit by the sparking plugs and, when the thermocouples indicate that they are operating satisfactorily, the main fuel supply is switched on to the burners. Other thermocouples indicate when combustion has been established in each chamber, and the turbine is then accelerated on the hand throttle valve.

The starting motor continues to assist the turbine until a speed of approximately 2500 rpm. has been attained, when the plant becomes self-sustaining and as its speed continues to increase, the starting motor is eventually disengaged by means of a free-wheel clutch. As the turbine speed approaches the no-load speed, the automatic governor assumes control of the fuel supply through the oil-operated throttle valve, the time required to reach the no-load condition being approximately one minute. Normally, the turbine is run for five minutes in this condition for "warming up" before load is thrown on to the machine. If necessary, however, the plant is capable of accepting full load without delay, the time required to bring it to the full load condition being approximately 1½ minutes.

No barring-over is necessary after the machine has been shut down, but the circulation of oil to the bearings is continued for a few minutes.

MISCELLANEOUS TESTS

The compressor and compressor turbine were tested as separate, independent units by the Bristol Aeroplane Co., Ltd. The results proved that the adiabatic efficiency of the compressor was 86 percent (against a design figure of 84 percent), while the compressor turbine exactly achieved the design efficiency of 85 percent at the designed point.

Tests on the combustion chambers at the normal working pressure, carried out by Messrs Joseph Lucas (Gas Turbines), Ltd., proved the combustion efficiency to be slightly in excess of 98 percent.

With the aim of reducing flow-path losses to a minimum, aerodynamic tests were undertaken by Messrs. Allen at their Bedford works on scale models of the compressor inlet and outlet ducting, the heat-exchanger return header and the power-turbine exhaust diffuser.

CONCLUSION

The outstanding success which has attended the development of this important project, brought to fruition in such a short space of time, has been achieved by concentrating on the problems of the gas turbine a team of able technicians and by the extension of Messrs. Allen's facilities.

A section of their Biddenham Works has been set aside for the assembly of gas turbines, and special machine tools for the manufacture of blading have been installed. In addition, on behalf of the Admiralty, they have built a fully-equipped test-house and the instrumentation provided will afford comprehensive data on every aspect of gas-turbine performance.

The work has been greatly facilitated by a consultancy agreement between Messrs. W. H. Allen, Sons & Co., Ltd., and the Bristol Aeroplane Co., Ltd., under which the Bedford firm receive design data, as well as advice in regard to methods of production and the use of certain special facilities for trials and testing.

PART LOAD CONSIDERATIONS FOR GAS TURBINE CYCLES

COMMANDER JOHN J. MC MULLEN, USN

THE AUTHOR

JOHN J. MCMULLEN, a native of Montclair, New Jersey, graduated from the U.S. Naval Academy and was commissioned an Ensign, U.S.N., in June 1940. After serving on various destroyers, he was ordered in 1943 to the Mass. Inst. of Technology for postgraduate training. In June 1945 he was awarded the degree of Master of Science in Naval Const. & Eng. by MIT. After a tour of duty at the New York Naval Shipyard he was ordered to the Swiss Federal Institute of Technology, Zurich, Switzerland, for further study in connection with gas turbines. He completed work on his doctorate (Doctor of Technical Sciences) and returned to the United States in early 1951. Since that time he has been assigned to duty in the Design Division of the Bureau of Ships in connection with the application of gas turbines to naval uses.

I. INTRODUCTION

In the final analysis, the most important consideration in any type of machinery is the regulation. The question "How is it controlled?" will in most instances usually decide whether or not a particular type of machinery will be utilized for a specific job. A great deal has been published on both the open and closed cycle gas turbine and the purpose of this paper is to give a general summary of the part load considerations involved in both types of cycles, with particular reference to the closed cycle, using a marine propulsion plant as an example.

If an introduction into a marine propulsion plant utilizing a closed cycle gas turbine plant is desired, it is suggested that the reader refer to "A Gas Turbine with Reference to A Cargo Vessel," Paper No. 4 presented at the annual meeting of the Society of Naval Architects and Marine Engineers on 15 November 1951.

II. PRELIMINARY CONSIDERATIONS

The present status of gas turbine development has not been attained without numerous "teething" troubles. These preliminary troubles which are always associated with new developments gave rise to criticism which was, in part, more destructive than constructive. Part of the failure of early gas turbine plants was due to the fact that regulation problems were only considered from a stationary standpoint; i.e., the transient phenomena and associated overstressing of the materials due to mechanical and thermodynamic causes were not given sufficient consideration. This fact is, in a way, understandable because in steam turbine experience such phenomena had occurred to a much lesser extent or not at all; in the case of steam plants, large output variations cause rapid changes merely in the turbines, whilst the boilers, economizers, superheaters, feed pumps, pipes and auxiliaries follows the changes much more slowly.

Even now, it is not possible to precalculate all of the transient conditions of such power plants on account of the many variables involved, the present lack of precise operating data and the difficulty of untangling the various factors involved. Furthermore no complete results have been published for either the open or closed cycles in this regard and even if available, it would be practically impossible to determine the relative influences of the different components. It is possible to approximately determine the effect of the more influential factors but the results of such estimates would have to be rigorously checked under actual operating conditions. The following example of the effects involved in a relatively simple instance show clearly how complicated such calculations can be. The chosen example is that of the changes which occur in the recuperator. The temperature of the tubes depends amongst other things on the pressure, velocity and temperature of the flow on both sides of the recuperator tubes; furthermore, on the temperature distribution in the gas itself and on the temperature gradient along the tubes. All these variables are interlinked as well as being cumbersome functions of time.

A more complex example is afforded by the rotating turbo-machinery because the individual shapes of the component elements (rotor, housing, blades, etc.) have a marked influence on the heat flow and temperature distribution. The impossibility of accurate calculation of such local temperatures and consequent distortions makes it necessary to leave adequate clearance for blading and rotor expansion. This is especially important where austenitic steel is used because this has a high coefficient of expansion and gives rise to differential stress problems. As a result of these larger clearances, assumed efficiencies must be conservatively estimated.

A simple example of how the pressure and other defining conditions of a gas vary with time whenever a change is introduced into the system is given in Section V-3 below. Such calculations may be carried out after an approximate determination of the time constants on the basis of the design dimensions. These calculations will serve for deriving a preliminary estimate of the variation of the temperature with time and of the stresses involved. During the transient period, distortions of the otherwise linearly associated cir-

cuit variables will occur; i.e., the cycle diagrams (in so far as it is possible to consider them) will undergo relative distortions.

A marine gas turbine plant has a considerable advantage over a stationary gas turbine plant from the point of view of regulation. In a stationary electrical power plant, the load changes are dictated from outside; i.e., by the consumers. These changes can occur at random; i.e., completely unexpectedly. In a ship, however, the changes are governed by the operating personnel and a constant watch on the control panel during a particular desired change enables overshooting of the mark and associated fluctuations to be avoided. Pressure fluctuations may cause surging of the compressors. These phenomena may, to some extent, be avoided by means of special safety devices, more reliably, however by experienced manipulation of the controls. It should, furthermore, be stressed that the replacement of automatic regulation by manual control eliminates a possibility of unstable regulation; this is so because the automatic regulation equipment involves "feedback" and is therefore liable to fluctuations.

III. CYCLE POSSIBILITIES

The most acceptable open cycle marine gas turbine plant is one with an independent output turbine. This permits a greater flexibility in maneuvering and in the control of the propeller RPM without disturbing the compressor group, which will be able to adjust itself to an optimum speed. This arrangement compromises the surging problem because the danger of auto-excited surging of all the units is increased when the compressor work is extracted from the LP turbine. When the load of the HP turbine (output turbine) is suddenly increased, the LP turbine will tend to experience a momentary decrease in output causing the compressors to deliver less, whereas they should deliver more because of the HP turbine load increase.

A further difficulty associated with the open cycle process using reheat is the regulation problem which arises with two combustion chambers in series with one another.

The above discussion of the open cycle assumes a two-shaft unit and temperature regulation. It is also possible in the open cycle to use flow control by regulating the weight rate of flow through the output turbine; either with a relief valve after the compressor or with a by-pass valve on the output turbine.

In contrast to the open cycle, it is not as necessary to use reheat in the closed cycle plant because the air rate of itself is smaller. The danger of aerodynamically excited surging is decreased because the flow conditions remain practically the same at all loads. The useful work is best extracted from the low pressure end of the expansion; that is, a LP output turbine. Thus, the closed cycle has the advantage of a stable compressor group much less affected by instantaneous changes in the useful output of the LP turbine.

It is interesting to note that the thermodynamic losses decrease slightly at part load for the closed cycle in contrast to the steam cycle, where there is a marked increase. This decrease for the closed cycle is caused by the greater

effectiveness of the heat exchanger and coolers at part load. The latter cause a lower temperature at compressor inlet and since the HP turbine inlet temperature is maintained constant, the efficiency is slightly increased (Carnot).

The following tabulation gives a qualitative comparison of equivalent closed gas and steam turbine plants at full and ⅛ load. One hundred percent signifies the heat content of the fuel oil. Ideal efficiency is defined as the efficiency of the idealized cycle with no irreversible processes (100 percent recuperator effectiveness, 100 percent internal machine efficiencies, and no pressure drops in the piping). The gas turbines closed cycle is assumed to operate between 650° C., and 20° C. with a pressure ratio of 4. The steam cycle is assumed to have a temperature of 450° C., 3 stage regenerative preheating and a steam pressure of 25 Kg/cm² and a condenser pressure of 0.1 Kg/cm².

	GAS TURBINE		STEAM	
	Full Load	⅛ Load	Full Load	⅛ Load
Fuel Oil	100	100	100	100
Ideal Efficiency (η)	62	63	40	30
Thermo Losses (100-η)	38	37	60	70
Mech. Losses	2(max.)	10	0.5	4
Other Losses	30	31	14.5	20
Useful Work	30	22	25	16

IV. DESCRIPTION OF OPERATION

The closed cycle plant has several possibilities of part load operation. For maneuvering and unexpected changes in load, it is possible to by-pass the LP turbine. This affords an instantaneous means of decreasing and subsequently, increasing the load. Generally, the LP turbine by-pass valve is linked with the LP turbine throttle valve in order to maintain approximately a constant pressure drop across the HP turbine. Since the weight rate of flow remains constant, the procedure can be repeated as often and as quickly as desired. The part load efficiency is poor because of the throttling process in the by-pass valve. It may be necessary, in very extreme cases, to install a by-pass cooler in order to prevent overheating of the recuperator tubes.

For expected permanent changes in ship's speed, pressure regulation is used; that is, the pressure level is varied by decreasing or increasing the weight rate of flow.

Decrease of the load can be accomplished through a relief valve on the high pressure side of the system between the HP compressor and recuperator, permitting release of the working medium and a corresponding decrease in pressure.

To increase the output, the pressure is built up with the air compressors, or, for rapid increases, with the air accumulator. For slow increases of load and to replace leakage losses, the compressors pump into the LP side of the system between the recuperator and the pre-cooler. The latter thus removes the heat of compression.

For rapid increases, air from the accumulator is injected into the HP

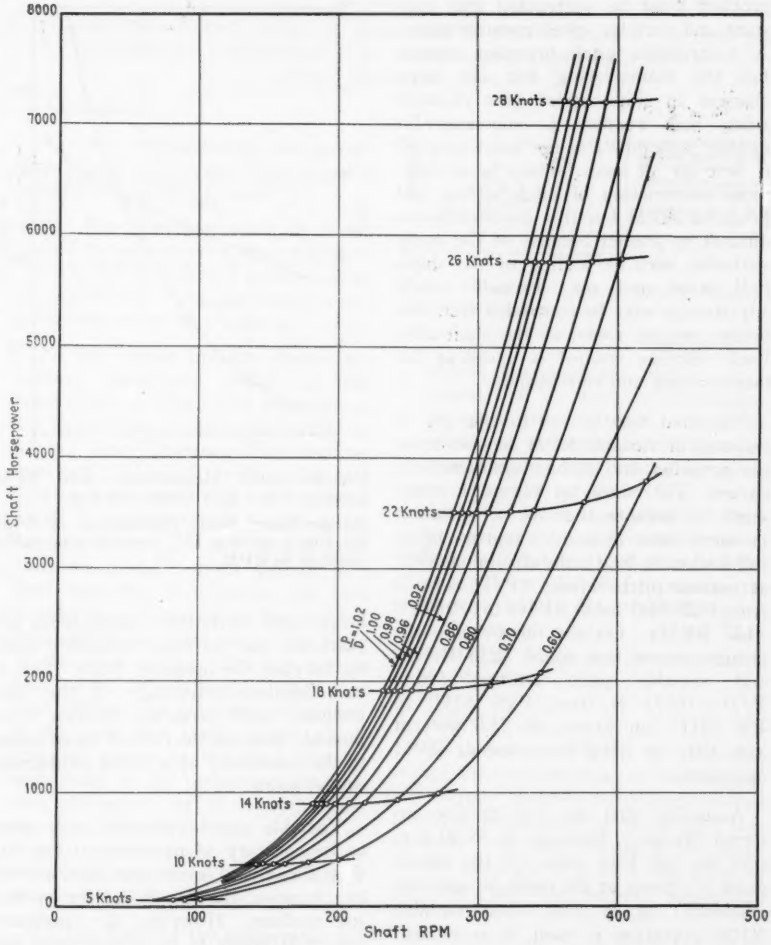

FIG. 1—PERFORMANCE OF A CONTROLLABLE-PITCH PROPELLER

This figure gives the horsepower absorbed by one propeller at various ship's speeds, propeller pitch settings (P/D) and shaft RPM. The data were obtained from self-propelled model tests and plotted by the David Taylor Model Basin, Washington, D. C.

side of the system between the HP compressor and the recuperator in order to obtain an initial positive load increase. Injection on the LP side of the system would give an initial negative effect because the turbine back pressure would be increased and the compressor action would be transiently compromised.

In discussing part load operation, the

problem must be segregated into constant and variable speed considerations. A controllable pitch propeller simplifies the maneuvering but for large changes in ship's speed (for example when bad weather is encountered), neither constant RPM nor constant pitch is best for all loads. There is an optimum combination of pitch setting and propeller RPM but this combination is difficult to predict because of the many variables such as fouling of the ship's hull, wind and sea. Propeller pitch adjustments may be controlled from the bridge, engine room, or the shaft-alley itself. Bridge control is excellent for maneuvering and emergencies.

The final decision as to the use of constant or variable RPM depends upon the propeller and turbine characteristic curves. The curves in Figure 1 would seem to indicate that for a variation in speed from 18 knots (approximately full load to ⅕ load), the change in SHP at normal pitch setting ($P/D = 1$) is from 1920 SHP (236 RPM) to 370 SHP (137 RPM). On the other hand, the change at constant speed (236 RPM) and variable pitch settings (from $P/D = 0.53$) is from 1920 SHP to 450 SHP; an excess of 21.6 percent (80/370) in SHP for constant RPM operation.

Assuming that the LP turbine internal efficiency decreases to 75-80 percent the full load value (if the design point is chosen at the point of optimum efficiency) at ⅕ load when variable RPM operation is used, it is evident that constant RPM operation can be, all in all, as efficient as variable RPM operation. However, as mentioned, there is an ideal combination which gives the best over-all efficiency and the final combination will depend mainly upon the propeller characteristics.

Thus, it is more conservative in the discussion of part load to consider that a normal pitch setting is maintained for

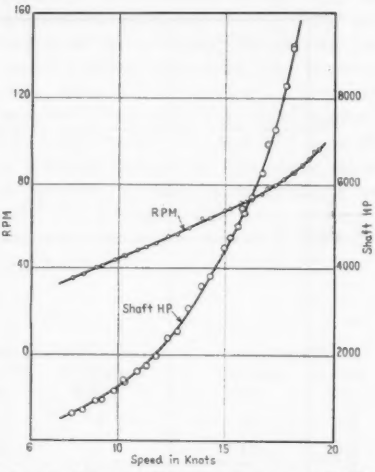

FIG. 2—SHAFT HORSEPOWER AND RPM CURVES FOR A C-3 CARGO VESSEL.

At the Rated Shaft Horsepower of 8,500, the ship's speed is 17.8 knots at a propeller speed of 84 RPM.

large speed variations; small speed adjustments can be more efficiently made by varying the propeller pitch. This is an additional advantage of the controllable pitch propeller, because it is possible to avoid the critical speed range of the machinery by a slight adjustment of the pitch.

Variable speed operation may seem to be contrary in principle to the fact that the closed cycle can load merely by changing the density of the operating medium. However, for shipboard use, it is better to be conservative and to accept the controllable pitch propeller primarily for its reversing feature. If operating results indicate that constant speed operation is preferable, the conditions can only be more simplified.

In general, cargo vessels follow the propeller law (Power proportional to the cube of the ship's speed) rather closely but in this case, the more accurate data from Figure 2 will be used.

V. CHANGE FROM STEADY STATE AT FULL LOAD TO STEADY STATE AT ⅛ LOAD (OR CONVERSELY), CORRESPONDING TO APPROXIMATELY ONE-HALF SHIP'S SPEED (PROPELLER LAW).

1. *Assumptions*

a) All temperatures remain approximately the same[1] that is, only pressure regulation is used.

b) The propeller pitch is maintained in the normal setting (P/D = 1). The RPM of the LP turbine varies in accordance with the ship's characteristic curves of Figure 2.

c) The circuit pressure under stationary conditions varies as the weight rate of flow. This presupposes the same circuit velocity and RPM as at full load. Pressure ratio remains constant. The LP turbine internal efficiency decreases with the variation in RPM because the unit is designed for maximum efficiency at full load. In cases where a great deal of part load operation is expected, the unit is sometimes designed so that its full load operating point is to the right of the peak of the efficiency versus load curve. In this way, a better part load efficiency is obtained. However, in the case of a cargo vessel which operates mainly at full load, the design point is for maximum LP turbine efficiency. At ⅛ load the efficiency of the LP turbine will be, as stated, approximately 75 percent of the full load value; in this case about 67 percent (0.75 × 0.90).

d) The speed of the compressor set driven by the HP turbine will be approximately constant for all loads. A slight speed variation (about 2 percent for ⅛ load) will, however, occur at part load to compensate for the increased percentage of mechanical losses (Absolutely, mechanical losses will remain roughly constant).

e) The compressor set is stable. This is shown in Figure 3 which gives the relative compressor and turbine characteristic curves. It is evident that an increase of compressor speed from n_1 to n_2 causes the compressor power requirements to increase beyond the turbine output at the same rate of flow (G); that is, point B is lower than point C. Thus, the compressor requires more power than is available and takes kinetic energy from the shaft, causing the latter to reduce speed back to n_1. A mathematical analysis of the self-stabilizing action has been given in the literature.[2]

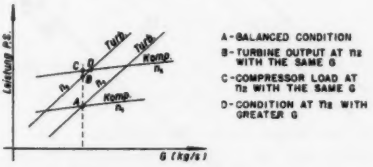

FIG. 3—RELATIVE COMPRESSOR & TURBINE CHARACTERISTICS.

2. *Effects*

As shown in Figure 4, this case causes the cycle diagram to move across the entropy chart to the lower pressure levels, as determined by the weight rate of flow. The only change in the shape of the diagram will be a variation in the low pressure turbine expansion,

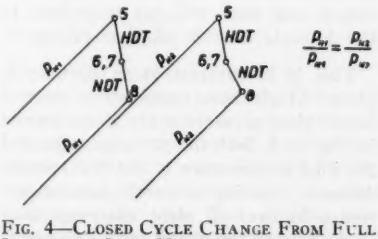

FIG. 4—CLOSED CYCLE CHANGE FROM FULL LOAD TO ⅛ LOAD UNDER STATIONARY CONDITIONS.

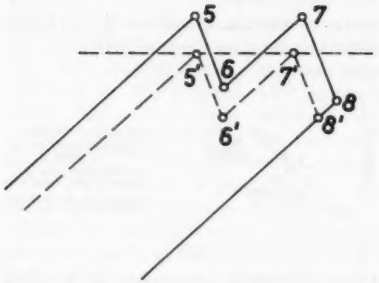

FIG. 5—OPEN CYCLE PART LOAD DIAGRAM SHOWING THE INFLUENCE OF TEMPERATURE REGULATION.

which will have a different slope due to the variation in internal efficiency. It should be noted, however, that after an initial rapid change (the so-called momentary effect), the changeover or transient period, equilibrium of the process is disturbed in a very advantageous fashion which tends to accelerate the transition.

The control of the process is quite simple because the HP turbine inlet temperature remains practically constant due to the stabilizing effect of the heat energy in the air heater (Large Mass).

The over-all plant efficiency will naturally be lower due to the decrease of LP turbine internal efficiency and the increase in the percentage of mechanical losses at part load. The HP turbine and compressor group will maintain about the same RPM and internal efficiency and thus, will not contribute to the decrease of over-all plant efficiency.

This is in contrast to an open cycle plant, which uses temperature control rather than pressure control. As shown in Figure 5, both the pressure ratio and the inlet temperature to the HP turbine decrease, causing a much greater decrease in over-all plant efficiency than in the case of the closed cycle (Carnot). In addition, it is more difficult to maintain a constant HP turbine inlet temperature in the case of the open cycle because a small variation in the fuel rate produces a large variation in temperature.

3. *Elementary discussion of the injection and "blow-off" processes.*

As mentioned in section IV above, the air from the accumulator is injected into the closed circuit immediately after the HP compressor into a space consisting of the recuperator, air heater and connecting pipes; V in Figure 6. The air enters at 1 and leaves at 2. It is assumed that:

a. The temperature at 2 remains constant because, as previously mentioned, the large mass of the air heater tends to stabilize the temperature.

b) Initially, the pressure at the LP turbine exit remains sensibly constant so that the weight rate of flow may be approximately assumed proportional to the pressure at turbine inlet. Therefore,

$$G_2 = G_o \cdot p/p_o$$

where

G_2 = weight rate of flow at 2

G_o = weight rate of flow in the steady state prior to change ($t = 0$).

p = local pressure in the volume V

p_o = local pressure in the volume V at time $t = 0$ when injection commences.

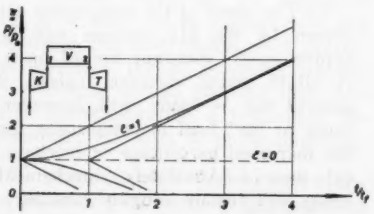

FIG. 6—DIMENSIONLESS DIAGRAM SHOWING PRESSURE CHANGE VERSUS TIME WHEN AIR IS INJECTED OR BLED FROM SYSTEM.

c) The "mixing" process in V is isothermal.

If G_1 represents the weight rate of flow entering the volume V, then the equilibrium condition before the change was

$$G_1 = G_2 = G_o$$

Since the "mixing" process is essentially an isothermal one, it follows from the gas laws that

$$G_1 = G_o \ \zeta/\zeta_o$$

Assume that the initial change of G takes place according to a linear law; i.e., that

$$G = G \ (1 \pm \varepsilon \ t/t_f)$$

where ε is a dimensionless constant symbolizing the rate of change of flow.

The plus sign signifies the injection of air and the minus sign the release of air (through the relief valve). t_f is the time to charge the Volume V when the weight rate of flow is G_o.

The effect of this linear change of G on the pressure p may be found from the following continuity equation.

$$(G_1 - G_2) \ dt = V \ d\zeta$$

$$G_o \ (1 \pm \varepsilon \ t/t_f) \ dt - G_o \ \zeta/\zeta_o \ dt = V \ d\zeta$$

Division by G_o/ζ_o gives

$$\zeta_o \ (1 \pm \varepsilon t/t_f) \ dt - \zeta dt = (V\zeta_o/G_o) \ d\zeta$$

The quantity $V\zeta_o/G_o$ represents the time t_f defined above. By introducing the dimensionless pressure or density ratio π, defined as

$$\pi = p/p_o = \zeta/\zeta_o$$

into the above equation, there results

$$t_f \frac{d\pi}{d\pi} + \pi = 1 \pm \varepsilon \ t/t_f$$

Solving

$$\pi = 1 \pm \varepsilon \ (e^{-t/t_f} - 1 + t/t_f)$$

The solution of this equation is shown graphically in Fig. 6. The influence of the volume V in delaying the pressure increase is thus seen. The diagram shows that the smaller the value of t_f, the more rapidly a given pressure increase will be attained. Small values of t_f are associated with small values of the ratio V/G_o. (The smaller the unit, the smaller the ratio V/G_o). The smaller V for a given weight rate of flow, the more rapidly can maneuvering operations be carried out.

Actually, of course, the injection process is much more complicated than assumed due, i.e., to the frictional resistances in the tube of the recuperator and air heater, as well as in the connecting piping. Furthermore, the temperature varies slightly and the turbine back pressure does not remain constant. It would be possible to allow for these influences by means of more complicated functions for G_1 and G_2.

VI. TEMPORARY CHANGE FROM FULL LOAD TO 1/8 LOAD (AND CONVERSELY) FOR MANEUVERING PURPOSES

1) *Assumptions*

a. The weight rate of flow in the closed cycle remains the same.

b. As previously mentioned, the by-pass valve and the LP turbine throttle valve are interlinked so that the pressure drop across the HP turbine remains approximately the same as at full load. Actually, as shown in Figure 7, the pressure drop across the HP turbine is initially slightly increased because of the decrease in total "resistance," when the by-pass valve is opened.

c. The inlet temperature to the HP turbine remains constant. The exit temperature from the LP turbine is much higher than at full load because the throttling process through the by-pass valve is at practically constant temperature; the final mixing temperature is approximately 90° C.

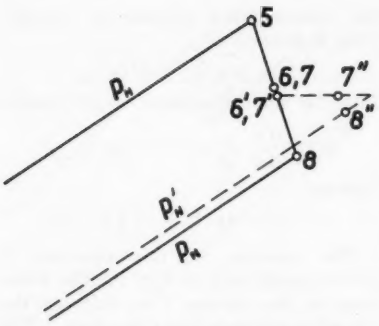

FIG. 7—CLOSED CYCLE MANEUVERING WITH BYPASS AND THE LP TURBINE VALVE.

higher than the LP turbine exit temperature at full load.

d. The heat exchanger effectiveness remains about the same as at full load. Therefore, the inlet temperature to the precooler is about 30° C. higher than at full load. This increase can be largely eliminated in the pre- and intercoolers. (Increase of cooling water and outlet temperature).

2) *Effects*

This case is shown in Fig. 7 and since only a small portion of the flow is utilized in the LP output turbine, it is obvious that the over-all efficiency will be poor. However, the procedure can be repeated as often and as quickly as required; this is ideal from the standpoint of maneuverability.

When the by-pass valve is opened, the total "resistance" of the HP turbine in series with the LP turbine and the by-pass valve in parallel decreases. This decrease can be considered in the design; but should it occur, the pressure drop in the HP turbine will increase and that in the low pressure will decrease (see Fig. 7). This is best explained by Figure 8 which shows the approximate turbine and compressor characteristic curves. It is seen that the opening of the by-pass valve with its associated initial decrease in total "resistance" will result in a lower LP turbine characteristic; in other words, a smaller pressure drop across the LP turbine (DE is less than AB). At the same time, the drop across the HP turbine is increased (EF is greater than BC). It is to be noted that this is an instantaneous effect. It is possible, that after a short period, the compressor curve in Fig. 8 would be higher, possibly resulting in an ultimately lower LP turbine exit pressure.

Since the main reason for utilizing the by-pass valve is for maneuvering purposes, the operation may, depending upon circumstances, be made in conjunction with the variation of propeller pitch. In fact, for all sudden changes in ship's speed, the combination of by-pass and propeller pitch control will generally be the initial method of operation because together they afford the fastest possible means of changing ship's speed.

This simple and instantaneous maneuvering (decrease and increase of load) cannot be accomplished with the open cycle. The load in the latter can naturally be decreased in the same manner (by-pass of HP turbine) but would

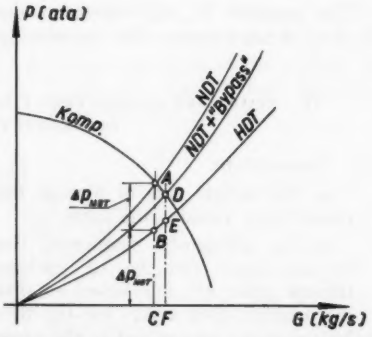

FIG. 8—RELATIVE TURBINE AND COMPRESSOR CURVES.
This shows the influence of the Bypass valve on the pressure.

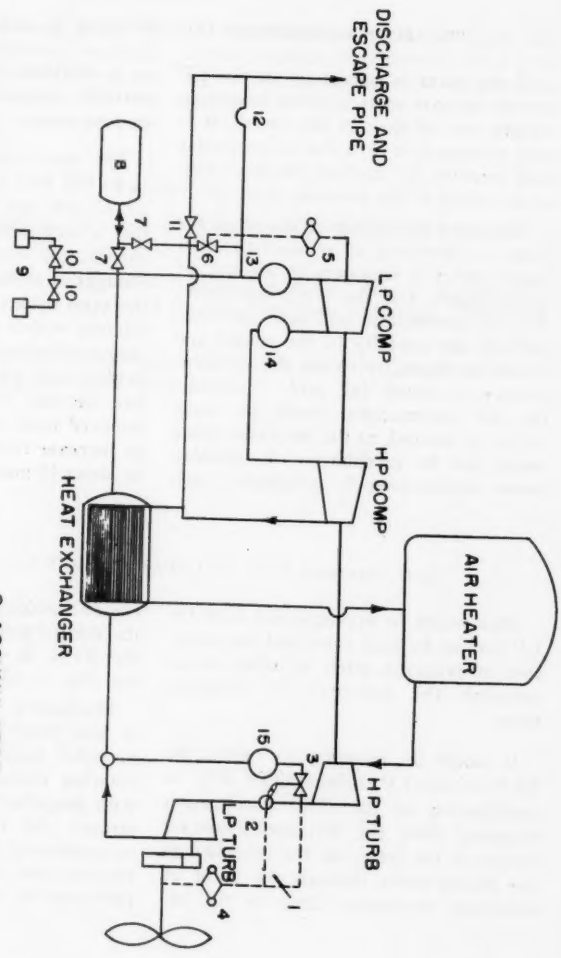

FIG. 9—CONTROL SYSTEM SCHEMATIC DRAWING FOR A CLOSED CYCLE MARINE GAS TURBINE SET

require three to four minutes to regain full load output.

Moreover, it is possible that immediately after a large open cycle load variation, the temperature in the HP turbine rotor will be higher than that of the working medium and the transfer of heat would momentarily be from rotor to working medium. As a result, there could be a fluctuation in temperature before the steady state is reached.

VII. SUDDEN UNEXPECTED INCREASE FROM ⅛ LOAD TO FULL LOAD

If the plant is operating on the LP turbine by-pass valve with the maximum weight rate of flow in the circuit, it is only necessary to close the by-pass valve and open the LP turbine throttle valve, as discussed in the previous case.

The other possibility occurs when the plant is operating at reduced pressure levels and it is necessary to use the air accumulators and the air compressors. The air accumulator will have only one-half the air capacity of the circuit and it will be necessary to use the air compressors to reach full load. Naturally, the air accumulator could be made larger, if desired, as the increased space would not be prohibitive. In general, when maneuvering is anticipated, such as in harbors, etc., the plant would be partially operated on the LP turbine by-pass valve.

The time required to increase from ⅛ to full load depends upon the capacity of the air accumulator. Provided that a sufficiently large accumulator is chosen, the closed cycle plant can be brought up to full load just as quickly as the open cycle; that is, in about 3 to 4 minutes which is more than ample for ship acceleration. However, in this particular case where the air accumulator has one-half the circuit capacity, the required time for the closed cycle plant to increase from ⅛ to full load would be about 15 minutes.

VIII. BACKING FROM FULL LOAD AHEAD TO FULL LOAD ASTERN

This would be accomplished with the LP turbine by-pass valve and the variation of propeller pitch in order to accomplish the maneuver in minimum time.

It would be necessary to reduce the RPM of the LP turbine about 30% in anticipation of the shaft acceleration resulting from the decreased resisting torque of the water on the propeller as the blades move through the point of minimum resistance. Due to the increased braking action of the blades in the normal position, it is faster to allow the RPM to decrease at normal pitch and then to adjust the blade pitch.

Emergency backing is accomplished in less time[3] with a controllable pitch propeller because the momentum of the rotating masses (turbine and shafting with propeller) need not first to be destroyed (by reversing). Furthermore, as mentioned, there is no time lag in the transmission of signals as the propeller pitch can be controlled from the bridge.

IX. CONCLUSION

The qualitative considerations of this discussion permit the conclusion to be drawn that the security of operation, especially from the maneuvering standpoint, is greater, the smaller the dimensions of the installation. This confirms our choice of the closed cycle, especially in regards the machinery.

It also leads one to the belief that for very large outputs, it would be preferable to generate the shaft horsepower output in a multiplicity of separate units, tending towards smaller dimensions (Stable operation!). While this might increase the cost of the installation in a stationary power plant it

is, however, the trend in ship design to have a power plant embracing a multiplicity of units. Particularly for naval vessels, which operate mainly at low part loads, this is an important consideration because it affords higher efficiency, security of operation and a strategic subdivision of the engineering spaces.

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TECHNICAL PROGRESS IN MARINE ENGINEERING DURING 1951

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For the purpose of this survey, the marine engineering activities of the past year can most conveniently be considered under three headings, *viz.*, machinery for tank ships, for dry-cargo ships and for special-purpose vessels. The year just closed has been indisputably a "tanker year," a large proportion of the shipbuilding contracts completed having been for ships of this class. In this connection, it is significant that the United States of America has recently become an oil-importing country, whereas, previously, oil was one of her exports—a circumstance which has occasioned certain changes in tank-ship design, particularly in regard to machinery installation.

Tank ships are now required to transport their cargoes over much greater distances than formerly, and fuel economy is vitally important, especially when the high power of the very large vessels of the class is borne in mind. Moreover, the size of these large, fast tankers (one of 31,000 tons deadweight was launched in Great Britain during the year, and two of 40,000 tons were ordered in Germany towards the end of 1951) calls for powers which bring them, with one or two exceptions beyond the point at which a single direct-coupled Diesel engine is a practical possibility at present. As yet, only the first few ships of the class have been delivered, and the full effect of the many orders for them will not be felt for some time. The large ore-carriers now being built present somewhat similar problems, and only those in the higher range of service speeds are to have steam machinery.

No such trend can be discerned in the sphere of dry-cargo ships. Some hitherto steam-minded owners (for example, the Booth Line and Messrs. T. & J. Harrison, Ltd.) have ordered motorships as well as steamships; while the Pacific Steam Navigation Company who, since the early 1920's, have had built for them only motorships, have taken delivery of a number of fast cargo steamships. The increasing cost of overhauls and voyage repairs, particularly when the vessels concerned trade to ports where embargoes on heavy cargoes are in force, have no doubt been a powerful factor in encouraging some owners to adopt steam-turbine machinery for installations of medium and large power. In Germany, where the two principal shipping companies have embarked upon an extensive reconstruction program, the decision to employ turbine machinery has been largely dictated by the grave shortage of Diesel-

trained engineers, consequent, to a large extent, upon the heavy losses of U-boats during the late war.

A wide range of machinery has been adopted for special-purpose vessels and, in this category, mention should be made of the series of passenger-cargo steamships being built in Scandinavia for the Finland-Stockholm services. These vessels are to be fitted with an improved form of quadruple-expansion engine, with inter-stage turbo-compression. We understand that this type of machinery was chosen for reasons of quietness of working, and also to assist continuous operation at very low speeds, in negotiating icefields.

Diesel-electric propulsion continues to be favored for ferry vessels, suction dredgers, United States harbor tugs and Mississippi "push boats," in which special maneuvering characteristics are required.

The year 1951 will be memorable not least in that, during its course, the first major gas turbine-engined ship has crossed the Atlantic. We refer, of course, to the oil-tank ship *Auris*, and even if the gas-turbine alternator set represents only one-quarter of the total power output, the good showing of the British Thomson-Houston gas turbine during the first voyage with the new prime mover augurs well for the future.

In the United States of America, the construction has begun of an atomic-powered submarine; and, though one's thoughts on this first application of a modern development in nuclear physics to marine propulsion must be tinged with regret, the technical achievement which its success will, in due course, represent, should stimulate endeavor in a wider field.

Developments in auxiliary equipment have kept pace with propelling-machinery progress, and the use of alternating-current systems for auxiliary power attracts increasing attention. The operating characteristics of deck machinery remain the principal impediment to the wider adoption of this simpler, less costly and generally more desirable method of power generation and utilization in ships; but leading electrical manufacturers, both in this country and abroad, are studying the problem closely in an effort to reduce the weight, cost and complication of a-c deck equipment.

STEAM TURBINES

There is no sign that, for merchant ships, markedly advanced steam conditions are gaining general acceptance in this country. As Captain (E.) W. Gregson, R.N.R., M.Sc. (Eng.), mentioned in his paper entitled "Oil-fired Marine Boilers," before the World Power Conference, the need to incorporate expensive alloy steels in superheaters does not arise with steam conditions below those represented by a pressure of 450 lb. per sq. in. and a temperature of 750 deg. F. In the higher-power range, however, the improved cycle efficiency associated with more advanced conditions, represented by 600-650 lb. per sq. in. and 850 deg. F., has justified the increased prime cost of the plant.

The "moderate" school of thought is exemplified in the liners *Kenya*, owned by the British India Steam Navigation Co., Ltd., and the *Ocean Monarch*, belonging to Messrs. Furness, Withy & Co., Ltd. In the former, steam at a pressure of 430 lb. per sq. in. and a temperature of 750/600 deg. F. is supplied to the single-reduction geared turbines of 11, 200 S.H.P.; while, in the latter, steam at a pressure of 425 lb. per sq. in. and a temperature of 750 deg. F. is supplied to the double-reduction plant, of 11,500 S.H.P.

There are, of course, exceptions, among which may be mentioned three 8000-S.H.P. sets of three-casing turbines, being built at the Trafford Park

Works of the Metropolitan-Vickers Electrical Co., Ltd. These installations, designed to take steam at a pressure of 600 lb. per sq. in. and a temperature of 950 deg. F., are intended for the *N*-class cargo liners of the Blue Funnel Line. Their construction is now well advanced and the first set is expected to undergo shop steaming trials early in 1952.

The important paper read in London before the International Conference of Naval Architects and Marine Engineers by Mr. Mark L. Ireland, Jr., on behalf of himself and his co-authors, and entitled "Higher Steam Conditions for Ships' Machinery," provoked a lively discussion, which amply demonstrated that interest in the question is very much alive in this country, even though a somewhat conservative policy is being pursued.

The trend in naval machinery was revealed in a paper before the Royal United Services Institution, in which Captain (E.) C. P. Gallimore stated that the anti-submarine vessels now projected would operate with higher steam pressures and temperatures than those employed in the present program of *Daring*-class destroyers, *viz.*, 600 lb. per sq. in. and 850 deg. F. Incidentally, the *Daring*, the flotilla-leader and first of the class to be completed, carried out preliminary trials off the Northeast Coast in the late autumn. Built by Messrs. Swan, Hunter and Wigham Richardson, Ltd., the vessel is propelled by geared turbines, constructed by the Wallsend Slipway and Engineering Co., Ltd., in accordance with designs prepared by Pametrada.

It is worthy of record that three different types of turbines will be fitted in the eight vessels of the *Daring* class, and we believe that a number of boiler designs will be represented—a circumstance which will provide data for a close comparison of the performance and practical merits of each design.

From the technical point of view, the most interesting geared-turbine plant completed in this country during the year under review is that installed in the oil-tank steamship *British Adventure*—the first of a series of 28,000-ton ships ordered by the British Tanker Co., Ltd. In this particular installation, built at the Barrow-in-Furness engine works of Messrs. Vickers-Armstrongs, Ltd., to design information provided by Pametrada, a 14-stage all-impulse h.-p. ahead-turbine is cross-compounded with a two-flow 15-stage all-reaction l.-p. ahead turbine. A separate h.-p. astern-turbine rotor, in a separate casing, is overhung, from the forward end of the h.-p. ahead-turbine shaft. Steam is admitted at a pressure of 420 lb. per sq. in. and a temperature of 740 deg. F. to the first h.-p. ahead stages, through 16 "always open" and nine adjustable nozzles. The fabricated l.-p. turbine casing, which houses a cast-steel barrel carrying all the ahead stationary blading, is supported at the horizontal center-line to reduce the effects of differential expansion and to preserve the alignment of the fixed and moving members under all conditions—a practice which follows the success achieved by the Pametrada single-casing turbines, described in Dr. T. W. F. Brown's paper on "Geared Steam Turbines for Merchant-ship Propulsion," before the North-East Coast Institution of Engineers and Shipbuilders, in 1950. The l.-p. astern element is arranged within the l.-p. ahead casing. The normal service power of the set, *viz.*, 12,500 S.H.P., is developed at a propeller speed of 112 rpm., the h.-p. turbine developing 7125 hp. at 3988 rpm. and l.-p. turbine 5375 hp. at 3662 rpm.

Steam is supplied by two Foster Wheeler D-type boilers, regulated by Bailey automatic combustion-control equipment. The boilers are installed on a flat aft of and above the articulated double-reduction gearing. The interesting alternating-current electrical sys-

tem is discussed in a later section of this survey, under the heading Electrical Equipment.

Mention of single-casing geared turbines recalls that, following the success achieved in the cross-Channel steamship *Brighton,* two further twin-screw installations of this type are being installed at Dumbarton in the British Railways' *Normannia* (for the Havre-Southampton service) and *Lord Warden* (a passenger and motor vehicle ferry).

In the United States of America, a 3000-S.H.P. single casing turbine has been built by the General Electric Company, Schenectady, for the re-engined Great Lakes vessel *Homer D. Williams.* In this particular set, the locked-train (or "dual tandem," which we are now informed is the correct term) double-reduction gearing employs pinions with teeth hardened to as much as 300/350 Brinell. A substantial saving in space has been achieved, not to mention a 50 percent increase in speed, with half the previous steam consumption. As great interest is at present being paid to the rejuvenation of the Great Lakes fleet of steamships, some of which are of considerable age, it can be reliably expected that further installations of this type will follow.

Among unusual turbine plants completed during the year is that of the French cable-laying steamship *Ampere,* a product of the Penhöet organization's Normandie Yard, at Grand-Quevilly, near Rouen. In this vessel, geared turbines drive Penhöet-Escher Wyss variable-pitch propellers, whereby, it is claimed, the necessary "creep" speeds for cable-laying operations can be obtained.

In regard to turbine sets of smaller power, the order which the Manchester Liners, Ltd., placed with Messrs. Cammell Laird and Co., Ltd., for a pair of cargo steamships, each of 2850 tons deadweight, deserves mention. With these ships—the first of which is to be aptly named *Manchester Pioneer*—the owners propose to enter the United Kingdom-Great Lakes trade. The vessels will undoubtedly provoke much interest, as turbine engines suitable for ships of this size have not been built in this country for some years.

A feature of many of the steam-turbine installations completed during the year has been the extent to which standard turbine frames were employed. Here, we see the influence of the Pametrada organization, which serves as a central design office for member firms of the Association. Examples of this may be seen in the 11,000-S.H.P. three-casing turbines in the 28,000-ton tank ships of the *Velutina* class, recently added to the fleet of the Anglo-Saxon Petroleum Co., Ltd. These turbines, with their articulated double-reduction gearing, are very similar to those installed in the Blue Star liner *Tasmania Star* (12,000 tons gross); while almost identical turbines, but with interleaved gearing, were fitted two years ago in seven new steamships of the Blue Funnel Line. Similarly, the largest tank ship so far launched in this country—the *World Unity*—will have two-casing machinery identical with that in the *British Adventure.* Many other instances could be cited to demonstrate this common-sense economy in design work, patterns and material. A parallel development in shore practice is the recent decision of the British Electricity Authority that, in future, only 30-MW. and 60-MW. turbo-alternators will be installed in their power stations.

As is well known, there are no foreign member-firms in the Pametrada organization, but, when the Anglo-Saxon Company placed the contracts under their £45 million program, for 46 new tankers, representing a deadweight capacity of 900,000 tons, it was agreed, in the interests of standardization, to release Pametrada design information to the four Dutch builders who received a proportion of this immense program. With one exception, the Dutch builders con-

cerned have been accustomed to constructing turbines of several types, *viz.*, Brown Boveri, Curtis, Parsons and Zoelly.

It is understood that Pametrada have granted general licenses to certain overseas companies, other than those concerned in the Shell program.

Though no turbo-electric vessel was delivered during 1951, five are now under construction, all having propelling machinery by the British Thomson-Houston Co., Ltd., of Rugby. They are the *Samoa,* for the Union Steam Ship Company of New Zealand, Ltd., and four tank ships in the large program of new construction undertaken by the Shell Group. Two of these turbo-electric ships, it should be mentioned, will be built in Holland.

An event which passed almost unnoticed was the Golden Jubilee of the pioneer turbine passenger steamship *King Edward.* Built at Dumbarton in 1901 for the then Turbine Syndicate, whose subscribers were Messrs, William Denny & Brothers, Ltd., as the shipbuilders, Sir Charles Parsons, representing the engine-builders, and Captain John Williamson, a Glasgow shipowner, this historic ship is still in service, with her original boiler and turbines, and it was altogether fitting that delegates to the International Conference of Naval Architects and Marine Engineers should have made an excursion down the Clyde in the vessel, during their short visit to Glasgow last summer.

By implication, the most powerful machinery to be installed afloat during the past year is that of the quadruple-screw passenger steamship *United States* (51,500 tons gross). Since she was floated out of her drydock building berth at Newport News on the 23rd of June, she has been referred to in the American Press as a contender for the Blue Riband, but details of her geared-turbine propelling installation have not yet been officially released. The vessel incorporates a number of defense features (including close watertight subdivision and "unitized" engine-rooms), and it is believed that the propelling machinery is similar to that installed in certain American aircraft carriers.

In the Orient liner, *Oronsay,* which entered service during the year, the 34,000-S.H.P. turbines and Foster Wheeler controlled-superheat boilers are virtually "repeats" of those installed in the *Orion, Himalaya* and *Chusan.* The boilers, generating steam at a pressure of 525 lb. per sq. in. and a temperature of 850/600 deg. F., are, however, fitted with oil-burning registers and atomizers which incorporate a number of Admiralty patents and are supplied by Associated British Combustion, Ltd., We learn that the *Oronsay* is shortly to be equipped with Denny-Brown anti-rolling fins.

An event which would have been of major significance, had not the designs been superseded by those of the 20-knot *Mariner*-class cargo liners, was the entry into service of the United States Maritime Administration's 18½-knot prototype cargo liner *Schuyer Otis Bland* (10,516 tons deadweight), in which the propelling machinery consists of a single-screw installation of two-casing double-reduction geared turbines, constructed by the General Electric Company and designed to develop 12,500 S.H.P. at 90 rpm. The turbines take steam at a pressure of 850 lb. per sq. in. and a temperature of 900 deg. F. from two Foster Wheeler D-type boilers. A particularly interesting feature of the installation is the method adopted for controlling the turbines. In place of the familiar ahead and stern throttle wheels, the main controls consist of two small levers, similar to those seen in a modern railway signalling box. The spherical-seated throttle valves open or close under the influence of a hydraulically operated follow-up system, in response to movement of the levers, which are, of course, interlocked.

RECIPROCATING ENGINES

The largest reciprocating steam engines built during the year were the Skinner Unaflow 10,000-S.H.P. units, built by Canadian-Vickers, Ltd., of Montreal, for the twin-screw train ferry steamship *Grand Haven*—claimed to be the largest vessel of the type in the world. In this ship, four Foster Wheeler D-type water-tube boilers supply steam at a pressure of 250 lb. per sq. in. and a temperature of 600 deg. F. to the two five-cylinder totally enclosed reciprocating engines, which develop their full power at 199 rpm. The vessel operates between Palm Beach, Florida, and Havana, Cuba—a distance of 270 miles, which is many times that of any train-ferry route in Europe.

In this country, orders continue to be placed for the justly popular North-Eastern Reheat engine, which is designed to maintain the superheated condition of the steam until it has completed its expansion in the l.-p. cylinder. Seven such sets of machinery, representing, in all, 13,428 I.H.P. were delivered during 1951 from the Sunderland Works of the North Eastern Marine Engineering Co. (1938), Ltd., and the associated firm of George Clark (1938), Ltd.

The cargo steamship *Crofter,* built and engined by Messrs. John Readhead & Sons, Ltd., South Shields, for the Harrison Line, Liverpool, is among ships in which a Bauer-Wach exhaust-steam turbine has been associated with a reciprocating engine—an arrangement which has gained much favor. It is gratifying to record the placing of an order for a combination of this type and one which, we are convinced, will be most successful in its own field and will, moreover, hold the interest and imagination of marine engineers. We refer to the Reheat reciprocating engine/Bauer-Wach exhaust-steam turbine installation which the North Eastern Marine Engineering Company are to construct for a cargo steamship of 7500 tons deadweight, ordered by Messrs. H. Hogarth and Sons, Ltd., Glasgow, from Messrs. William Pickersgill and Sons, Ltd., Sunderland.

Only one paddle steamship is at present being built in Great Britain, *viz.,* that which the Railway Executive have ordered from Messrs. A. & J. Inglis, Ltd., Pointhouse, Glasgow, to augment the coming season's sailings in Loch Lomond.

BOILERS

The principal types of boilers continue to have wide application, but a feature of the year has been the increasing popularity of the Babcock & Wilcox integral-furnace boiler which has been installed in this country in such ships as the Tyne-built French passenger liner *Provence,* the Union-Castle liner *Rhodesia Castle* and the Swedish-Lloyd steamship *Patricia;* and, in the United States, in the large passenger steamships *Constitution* and *Independence,* of the American Export Lines. Each of the last-named two ships has four boilers of this type, generating steam at a pressure of 627 lb. per sq. in. and a temperature of 840 deg. F. This simple boiler design has much to commend it, with its almost vertical tube-nest promoting rapid circulation and freedom from operating difficulties.

Three Velox boilers, each with an evaporative capacity of 30 tons per hour, are being installed by the Compagnie Electro-Mécanique in the steamship *Ville de Tunis* (14,500 S.H.P.), being built at the Lorient Naval Yard for the Compagnie Générale Transatlantique. These boilers supply steam at

a pressure of 800 lb. per sq. in. and a temperature of 895 deg. F. In a similar ship—the *Ville de Marseille*—now in service between Bordeaux and Casablanca, three F.C.M. 47/60 all-water-wall boilers generate steam at the same conditions. Similar, but more highly rated, boilers are installed in the *Côte d'Azur*, a notable cross-Channel steamship, completed for the French National Railways during the year.

It is worthy of note that in Germany, where, before the war, very advanced steam conditions were adopted—often without appreciable gain in efficiency or economy — much more moderate tendencies now prevail. The new Hamburg-America liners will have Babcock-type boilers generating steam at a pressure of 640 lb. per sq. in. and a temperature of 840 deg. F., while the "monster" tankers being built at the Howaldtswerke are to have two-drum water-tube boilers of the shipbuilders' own design, operating at a pressure of 610 lb. per sq. in. and a temperature of 840 deg. F.

DIESEL ENGINES

Advances in marine Diesel engineering have followed the natural course of development. At one end of the scale, manufacturers have directed their efforts towards increasing the specific outputs of their products, while at the other, they have striven to reduce running costs by extending the application of low-grade fuels. Most builders of four-stroke engines have taken the course of increasing the ratings of existing models by the application of pressure-charging, in various forms; only in the smaller engines have entirely new models been introduced.

The burning of residual fuels continues to interest many engine-builders; and leading manufacturers of the larger units, who have established that their engines may be successfully operated with high-viscosity fuels, are continuing research with even heavier grades, in the expectation that the increasing demand for lighter fractions (for use in aircraft and automotive equipment) will result in an even greater surplus of heavier residuals.

The use of heavy fuels is being extended to the higher-speed propelling engines, such as the Sulzer units (of 225 rpm.) in the Federal Steam Navigation Company's cargo ships *Cornwall* and *Surrey*, each of which has a geared Diesel installation. It is not only in Europe that this trend is seen, for the Great Lakes bulk-carrier *Eugene W. Pargny*, until recently a steamship, but now a motorship with a Hamilton-M.A.N. geared installation (with an engine speed of 240 rpm.), is also to burn low-grade fuels.

Nearly all the manufacturers of large marine engines have developed frames of all-welded design, for one or more of their ranges.

A feature of the year has been the efforts made by a number of important engine-builders to increase the output of their two-stroke cycle engines by the application of supercharging. The principle has been successfully applied in most of the M.A.N. two-stroke cycle engines—both single-acting and double-acting—which the firm have built since the war. In the M.A.N. system, a so-called rotary slide valve is incorporated in the passage between each exhaust port and manifold. In the single-acting engine, the valve is timed to close before the rising piston interrupts the air supply through the scavenging-air ports. A 15 percent increase in output, above that of the previous model, with a smokeless exhaust, is claimed.

Messrs. Burmeister & Wain have carried out promising experiments at Copenhagen with a modified version of

one of their standard 674-VTF-160 engines. Here, the delivery from the Büchi turbo-charger is conveyed, *via* inter-coolers, to the engine-driven rotary blowers with which these engines are normally fitted. It has been found that, as the output increases, the power absorbed by the mechanically driven Roots blowers becomes progressively less, until they are virtually running unloaded, with a consequent increase in overall mechanical efficiency and reduced fuel consumption. A continuous service output of 1250 B.H.P. per cylinder at 115 rpm., representing a B.M.E.P. of 101 lb. per sq. in., has been attained, against 922 B.H.P. (B.M.E.P., 74.5 lb. per sq. in.) of the unmodified model—a gain of 36 percent in output.

In Holland, the Werkspoor-Lugt engine, designed by the late Mr. G. J. Lugt during the German occupation of the Low Countries, and projected from the outset as a supercharged unit, has now undergone exhaustive trials. In this engine, a turbo-blower operates in parallel with the reciprocating scavenging-air pumps, driven from the crossheads. In engines embodying the principle of uniflow scavenging, such as the last-mentioned two, the degree of supercharge may be conveniently controlled by modification of the exhaust-valve timing.

Turning to higher-performance four-stroke cycle engines, the Nordberg Supairthermal engine, introduced during the year, is of considerable interest, in that it is claimed to develop one-third more power than the corresponding turbo-charged model, without greater transfer of heat to the cooling water and without increase in working-surface temperatures.

The Supairthermal engine incorporates the Miller system of supercharging. In this system, the cylinder is partially cooled, internally, by the large excess of scavenging air provided by a turbo-charger, which delivers at a considerably higher pressure (15 lb. per sq. in.) than hitherto. The increase in the air mass (about 30 percent) enables a correspondingly increased quantity of fuel to be burned. An intercooler serves to reduce the temperature of the air charge admitted to the cylinder from about 160 to 100 deg. F., with cooling water at 90 deg. F. The inlet valve is timed to close well (45 deg.) before bottom dead-center on the intake stroke, and the consequent expansion of the air charge from a pressure of 15 to about 6 lb. per sq. in. results in a further reduction of the air-charge temperature of about 50 deg. F. The B.H.P. per cylinder at 450 rpm. has been raised from 150 to 200 without increase of the peak pressure attained.

The actual timing of inlet-valve closure is variable, depending upon the pressure in the intake manifold, which, of course, being maintained by a turbo-charger, is a function of the load. At partial loads, the point of closure is progressively retarded until, at a manifold pressure of 6 lb. per sq. in., it is the same as in the normal turbo-charged engine. An eight-cylinder direct-coupled marine version of the Supairthermal engine (13 in. bore by 16½ in. stroke), developing 800 B.H.P. at 300 rpm., is being installed in an American tug. The method is also being applied to larger engines (16 in. bore by 22 in. stroke) in the Nordberg range, covering powers of up to 3200 B.H.P.

One of the most remarkable Diesel engines ever constructed is the M.A.N. six-cylinder KV 30/45 pressure-charged unit, of which prototype tests were completed last year. This engine (300 mm. bore by 450 mm. stroke) is of the welded-frame crosshead type, and, on moderate dimensions, it has returned the truly remarkable continuous rating of 1360 B.H.P. per cylinder at 428 rpm., representing a B.M.E.P. of 213 lb. per sq. in. That this has not been obtained at the expense of efficiency is shown by the fact that the

corresponding fuel consumption is 0.312 lb. per B.H.P.-hour. It is understood that the engine has been operated for short periods with brake mean effective pressures of up to 340 lb. per sq. in.

The high charging pressure employed —about 17 lb. per sq. in.—is provided by an exhaust-gas turbo-compressor, with multiple stages in both driving and driven components. Mounted at the back of the engine, the exhaust turbine, which rotates at 15,000 rpm., has five stages and is directly coupled to a blower having nine axial stages and one radial stage. An interstage cooler is neatly incorporated between the axial and radial stages, and the air charge passes through a second-stage cooler before entering the cylinders. The makers state that they intend to offer the engine for geared marine propelling installations and that a similar, but somewhat larger, model is also projected.

The largest Diesel engines which have been sent to sea in the period under review were the two Fiat double-acting two-stroke cycle 12-cylinder units installed in the Italian passenger liner *Giulio Cesare* (25,000 tons gross), which made her maiden voyage at the end of September. These two engines were built so long ago as 1942, as part of a naval project which was subsequently abandoned. With cylinder dimensions of 650 mm. bore and 950 mm. stroke, these engines have an output of 13,000 S.H.P. at 160 rpm. in service. During sea trials, the vessel attained a speed of 26.1 knots at an output of 20,000 S.H.P., at 192 rpm. Scavenging air is supplied by means of independent Diesel-driven reciprocating pumps. A sister ship, the *Augustus*, will be delivered early in 1952 from the San Marco yard of the same builders, the Cantieri Riuniti dell'Adriatico.

Of recently introduced designs, the new Harland-B. & W. opposed-piston eccentric-type engine continues to gain ground and several examples of this version of a well-tried engine have been installed in the standard tank vessels built at Belfast for various Norwegian owners. In most instances, these were seven-cylinder units of 750 mm. bore, with a combined piston stroke of 2000 mm.

Other large two-stroke cycle installations include those for two single-screw 29,000-ton tank ships, each of which is to be propelled by a B. & W. single-acting, two-stroke cycle, 12-cylinder engine. A twin-screw 31,000-ton tank ship, launched at Saint-Nazaire, France, has Schneider-B. & W. engines developing an aggregate of 13,560 S.H.P. for a service speed of 15 knots.

A smaller type of engine, built under license by Messrs. John G. Kincaid & Co., Ltd., Greenock, is the Polar T-size with a bore of 500 mm. and a stroke of 700 mm. The British Indian Company's twin-screw passenger and cargo motorship *Mombasa*, intended for the East African coasting service, in anticipation of developments expected from the groundnuts scheme, has an installation of this type. The ship is at present engaged on the inter-Pakistan route between Karachi and Calcutta.

Engines of this type, which are also built, under license, by Messrs. William Gray & Co., Ltd., West Hartlepool, are finding useful employment for geared installations. The tank ship *Bernhard Hanssen*, with twin Gray-Polar six-cylinder engines, was delivered in the autumn, when order for six similarly propelled ore-carriers, for the British Iron and Steel Corporation, were placed with these builders.

Coming now to engines in the smaller-power range, the Clark-Sulzer S.D. 36 engine is gaining favor for ships engaged in coastwise service, and here, again, orders have been received for twin-geared units for Norwegian vessels trading to the Great Lakes.

The first production model of the Werkspoor-Lugt engine has undergone tests, which were witnessed by inter-

ested parties from all over Europe. The engine was subsequently installed in the Dutch motorship *Prins Frederik Willem*. Readers may recall that, in our review last year, we commented that no order for an engine of this design had then been placed. We are glad to record that several of these interesting engines are now in hand, including a 12-cylinder unit developing 9600 S.H.P.

GAS TURBINES

An Anglo-Saxon oil-tank vessel has again made motorship history. In the late autumn of 1951, the *Auris* crossed the Atlantic, with her new gas turbine providing part of the propelling power during the 21-day voyage from the Tyne to Port Arthur, Texas. The pioneer motorship, it will be recalled, was the same owners' *Vulcanus,* and it is appropriate that the first ocean-going merchant ship with gas-turbine propelling machinery (though admittedly only one-quarter of the whole) should belong to the same enterprising concern. Originally powered entirely by Diesel-electric machinery, the *Auris* had four Hawthorn-Sulzer/B.T.H. 830-kw. Diesel alternator sets, which supplied electrical energy to a double-armature propelling motor. Following extensive trials at the works of the British Thomson-Houston Co., Ltd., Rugby, a gas-turbine/alternator set with the same output and electrical characteristics was installed in place of one of the Diesel-/alternator sets, the work having been entrusted to Messrs. R. & W. Hawthorn, Leslie Co., Ltd., the builders of the ship.

Throughout the transatlantic crossing, the gas turbine ran continuously, the output of the set having been reduced only to the extent expected because of an air-temperature rise of some 29 deg. F.

Research has continued with the Pametrada 3500-S.H.P. gas turbine, including runs over extended periods. The Rover gas turbine, installed, in 1950, in the demonstration launch *Torquil,* has been modified, and a single-screw version (without auxiliary propelling power) has been fitted in H.M. *Harbor Launch 3964*—a 51-ft. dockyard picket boat, operating from the Coastal Forces Base, Gosport. Meanwhile, work has continued on the twin Metropolitan-Vickers units which will be installed in a motor torpedo-boat, and with the Rolls-Royce gas turbines which are to re-engine one of the famous steam gunboats, which were so well described in the paper entitled "Steam Gunboat Machinery—a Light-weight Steam Plant," presented by Commander (E.) H. A. K. Lay and Commander (E.) L. Baker, D.S.C., to the Institution of Naval Architects, in 1948.

The English Electric Co., Ltd., of Rugby, have in hand a 6000-S.H.P. gas turbine/alternator set which is to replace a power unit in one of the twin-screw turbo-electric lease-lend *Captain*-class frigates.

Details have been released recently of the 1000-kw. gas-turbine/alternator set which Messrs. W. H. Allen, Sons and Co., Ltd., Bedford, have constructed to the order of the Admiralty. This open-cycle unit, with a single-stage heat-exchanger, follows the simple series arrangement of co-axial compressor and power turbines, and has, we understand, given very satisfactory results. A feature of the set is the employment, for the first time in this country, of Stoëchicht epicyclic gearing, giving a very compact transmission. The characteristics of the gear are such that, with the power turbine rotating at 6750 rpm., the speed of the alternator shaft is 1500 rpm. The Bedford firm, it may be added, are licensees for gears of this design, which has interested other builders of turbine machinery, on account of its possible future use in connection with marine turbine drives.

VARIOUS DEVELOPMENTS

In the United States of America, the Navy authorities have placed an order for a submarine in which the power for propulsion will be derived from an atomic-energy plant. We learn that the project is several months ahead of the planned program, in which completion at the end of 1952 was envisaged. The hull is being built by the Electric Boat Company, and the list of firms associated with the manufacture of the propelling equipment includes such well-known names as those of the Westinghouse Electric Corporation, New York and the General Electric Company, Schenectady.

The principle of the heat pump, employed in cooling the Royal Festival Hall in summer and in heating it in winter, is being applied in H.M.S. *Vidal* —a new survey ship now being completed at Chatham. The air-conditioning plant installed in this vessel will provide equable conditions throughout the living and working spaces and offices, in all climates from the equator to the poles. Its capacity is 750,000 B.T.U. per hour; a saving of as much as 100 kw. in the electrical load is anticipated from the development.

NAVAL ENGINEERING MANPOWER

Comment From The Field

LAURIE R. WALLACE

THE AUTHOR

Early training consisted of seven years in the design section of Morse Dry Dock and Repair Co., Brooklyn, N. Y., special courses in Naval Architecture and Marine Engineering at Pratt Institute, Brooklyn, N. Y., about 16 years in Building Construction. From early 1937 to date, Civil Service with the Navy, seven years of which was in the Design Section Engineering at the Brooklyn Naval shipyard and since February, 1943, to date, in the office of the Assistant Industrial Manager, U.S.N., 6 N.D., and Design Senior Civilian in the Office of the Supervisor of Shipbuilding & Naval Inspector of Ordnance, Jacksonville, Florida. He is a member of the Florida Engineering Society, The Propeller Club, Port of Jacksonville, and an Associate Member of the U. S. Naval Institute. His home is in Jacksonville, Florida.

In view of the brilliant documentary account of "Meeting a Manpower Crisis in Naval Engineering," as portrayed by Nathaniel Stewart, and published in the November, 1951, edition of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC., it is felt that a few comments from the field on this subject may be helpful in furthering the Navy's best interests at the present time and into the future.

As a compliment to Nathaniel Stewart for the very sensible arrangement of his subject, it is perhaps best to arrange the following comments to follow in the same order.

THE SETTING

The average Navy Field Office is concerned with the Activation of Reserve Vessels, Conversions, Repairs and Overhauls and in some cases, the joint duties of Supervisor of Shipbuilding and Inspector of Ordnance for the Administration and Supervision of New Construction.

EARLY CALL TO ACTION

Upon the outbreak of the Korean hostilities, those Field Offices that had participated in the War Mobilization Planning for their areas, immediately scanned the manning tables based upon maximum production under their jurisdiction, with a view towards enlarging the staff and in some cases looking for a place to locate the enlarged staff.

TAKING INVENTORY

In some areas taking inventory of the technical staff in those offices that still existed at the time of the outbreak of hostilities in Korea was a very simple matter. The men could be counted on one hand, and quite often were engaged in a multitude of minor details that keep them employed, however, it is not to be construed that they were not fully occupied when the economy wave cut down the Navy staff. That cut was right to the bone, "and I mean bone." A rule such as "no person shall be retained on the Civil Service payroll for what he knows or can do, but what he does do," was followed.

The above quotation may not be correctly worded, but it is, as the writer remembers it, and to this day it sounds just as foolish, or hindsighted, as it would have been to say, "No naval vessel shall be maintained in Reserve status, the war is over, scrap them, we shall not need them any more."

The Navy lost many of its best hotshot designers to commercial interests by the above action, and in some cases they were replaced by inexperienced veterans, so the inventory was simple.

OPERATION DESIGN

Manning the vacancies to be filled in the Field Offices is predicated upon the assigned projects and contemplated enlargement of local contractor's facilities to accomplish awarded contracts for Naval construction. In some cases, old hands have been brought back into the fold. Promising young veterans familiar with the Navy's electronics have been captured by far-sighted officers, in most cases prior to the Korean incident, and of course a few misfits have appeared here and there among a crop of good men who are entirely green to naval construction, but they, because of their sterling qualities and abilities in other lines will pan-out immensely to the Navy's advantage. It is hoped that the methods outlined will suffice for the present emergency. However, in the long run, if there is to be a long run to this emergency, it will be necessary to replace old hands and possibly young Reserve Officers recalled to the colors for active duty, by training methods outlined by Nathaniel Stewart for the large Naval Shipyards. This will be better than bringing in "Experts" from out of town, because nothing disrupts the morale of an organization as much as having a supposedly superior person injected into the office at a higher salary than some of the incumbents, who feel that they did not have the opportunity to get promoted.

INCENTIVES

To the real engineer, which includes Naval Architects, the incentive in spite of the red tape of Civil Service, is, in the words of Herbert Hoover, "Fascination," and to further quote Herbert Hoover* "The engineer has the fascination of watching a figment of his imagination emerge with the aid of science to a plan on paper, move to realization in cement, metal or energy, bring new jobs and homes to men. That is the engineer's high privilege among professions."

* The quotation from Herbert Hoover's speech was taken from the December 13, 1951 issue of Engineering News Record, with the permission of the McGraw-Hill Publication Co.

The profession, however, has woes. The engineer's work is out in the open where all men can see it. If he makes a mistake, he cannot bury it in a grave; obscure it by trees and ivy; blame it on the judge or jury; claim his constituents demanded it, blame it on the devil; nor can he, like the public official, change the name of it and hope that the voters will forget it. Worse still, if his works do not work he is damned, and the world mostly forgets the name of the engineer who did it. If it works, the credit goes to some fellow who used other people's money to pay for it. But the engineer looks back at the unending stream of goodness that flows from his successes with a satisfaction that few other professions can know.

Big factor—most people are not aware of it, but the engineer is also a political, economic and social force. I asserted one time that he is the fellow who really dissolves monopolies, redistributes the wealth, and dismantles political platforms. Over our history, men of one generation after another have been elected to office by being "agin" the monopoly of canals, or railroads, or anthracite coal, or kerosene, oil or slums or the utility grabbing of water power. These were no doubt great evils, but who remedied these evils? It was the engineer.

A great "aginner"—he upset the canal monopoly with the railways; the railways with the automobile, the airplane and the pipeline. He upset the anthracite monopoly with coke, the kerosene oil with electric light, and he assured that most of the streams would remain as scenery by making cheaper power with steam.

Who makes possible the escape from the slums? It is the engineer with his parkways, his bridges, his satellite towns. Who provided leisure for the housewife? It was the engineer with his household gadgets.

I hardly need add that it was the engineer who distributed wealth by creation of mass production and his many other devices to reduce costs of production.

ENGINEER TRAINING NEEDED

The training of engineers instills character in those who would join the ranks. High ethical standards are the essential of all professions, engineering included. Technology without intellectual honesty does not work. Construction without consciousness soon crumbles.

These are the reasons you have no engineers before the Kefauver Committee, nor in the headlines which these days pour forth from grand juries and district attorney offices. The engineers merit only to sit on juries.

But, here we meet a great national problem. We do not have enough engineering teachers and we do not have enough students to carry on the nation's work. And we do not have enough research facilities to assure the needed flow of new inventions and improvements.

ADDITIONAL INCENTIVES

Patriotism, security and congeniality of working among your fellow men that talk your language technically, and the possibility of promotion.

Although the possibility of promotion is mentioned as an incentive, it is only a possibility in the Field today, because of apparent conflictions in the interpretations of Civil Service rulings that seem to have been made to fit too many special cases without being able to show any goal to aim for that will lead

to the top of the profession. There is a small salary increase given annually (or at eighteen months for GS-11s and above) which does not begin to catch up with the increasing cost of living. There seems to be no normal way to be promoted because a satisfactory method of Efficiency Rating has not yet been devised. The old system with its five main divisions, Excellent, Very Good, Good, Fair and Unsatisfactory, seems to have been discarded because of Bosses—Pet Favoritisms, for a very loose, almost socialistic system that states that the employee is either Outstanding, Satisfactory, or Unsatisfactory. In other words, a man or woman is either so very excellent that his boss will have to prove it in writing, which must be substantiated in turn, in writing, by the Boss's boss, all the way up to the Head Man of the district. This "stick your neck out" process must also be followed to get rid of, or demote an unsatisfactory employee, so in the vast middle category are 99⁹⁄₁₀% more or less of "satisfactory" employees who have no hope of getting a promotion from one grade up to another, other than the small increment, which only amounts to about 3% extra take home pay.

The security factor of Civil Service employment in the Field today means nothing insofar as Engineers employed by the Navy is concerned, because the economy reduction in force procedure showed clearly, that, permanent positions could be abolished at the whim of anyone in command. In some cases good men were retained 2, 3 and 4 grades below their previous permanent grade. Then when the Korean affair started these same people were promoted "Temporary" back to their old grade and told that in case of another future reduction in force they would revert back to the lower rate and could never again be a permanent employee at their original grade before demotion because certain dates for such changes were in effect at such and such time and on and on until one felt like he was listening to a man choking himself goggle-eyed with red tape.

After many years of such experiences, one comes to the conclusion that the ever changing rulings of the commission fail to show any stability for the future. It is taken for granted that the commission is staffed by some of the best brains available in personnel matters, but the intent and purpose of the whole system seems to indicate that no provision has been made to take care of and take cognizance of the large increase in value of a creative worker, like the Engineer, or other professional employee, over the strictly service type of employee whose working life cycle can usually be plotted as a fair curve that rises gradually to its peak at about 15 to 20 years of service and then slowly drops off to a point somewhere near the retirement age. The service type of employee has a value to his unit, or department, about similar to his efficiency curve.

On the other hand the creative worker is quite often of less value than his experience in the service indicates for the initial period of his employment. This is as Mr. Stewart noted when he indicated under "Incentives" the costs of orientation of a new employee in the design section. However, from there on out his value to the Navy often gets way ahead of his salary, or "General Service" rating and in some cases this value reaches salary brackets that would stagger the imagination of the Area Wage and Classification Officers, who have stated on one occasion that they do not have any technical men on their staff, but judge a man's value by "factors"?

This condition of holding a creative worker in the same category as the service worker has resulted in the loss to the Navy of some of its best technical brains to commercial interests who can

and will pay in accordance with value given.

This has further resulted in what should be considered the disgraceful situation that has made it necessary for the Navy to have to resort to contracting at high costs for the Navy's own ships, designed by outside private yacht and ship architects who employ Navy-trained professional and semi-professional workers at a higher salary than the Civil Service rates will pay. These same workers would rather work for the Navy except for the flip-flop rulings and petty restrictions, such as time clocks, etc., that gall a man to ulcers long before his time.

That seems to be the picture in the Field, and it is not likely to change much for the better unless the Powers that be can devise a system that will again separate the professionals and semi-professionals from the purely service type of employee, insofar as Incentives and Efficiency Ratings go, so that the man that is a willing ambitious worker can see his way into the future to a point comparable in earnings and social status to the best technical men outside of the Civil Service system.

CHARACTERISTICS AND DEVELOPMENT OF NAVAL FUEL OILS

ACKNOWLEDGMENT

This article was written by MR. M. BLANCHIER, and it is reprinted from "The Institute of Marine Engineers Transactions" for October 1951.

INTRODUCTION

It is the purpose of this paper to review certain fuel characteristics to which technical aspects of fuel utilization lend a very special significance.

Sulphur is certainly one of the most undesirable elements to be found in a combustible, whether the fuel be for use in boilers or Diesel engines. If, unhappily, its presence has to be tolerated to some extent in order to avoid undue restriction of supplies in these difficult days, it is nevertheless essential to ensure that the sulphur content should not exceed a certain maximum percentage.

With regard to sodium, the adverse effects of introducing this alkali into the furnaces of boilers are well known. Indeed, it seems probable that the presence of sodium is also responsible for certain difficulties in the use of heavy fuels for Diesel engines. It is, therefore, of prime importance that measures should be taken to prevent, or to minimize, its presence. In the first place, only a small proportion of sea water should be allowed in fuels, and secondly, a maximum ash content should be fixed.

At the present time, however, the question which raises the most serious difficulties is that of pumping fuels at low temperatures. The fact is that there is as yet no standardized method on the basis of which the future development of the pour-point of a mixed-base fuel—that is, of an asphalt-paraffin base fuel—can be predicted. But investigations are now being undertaken to develop a method of thermal pretreatment by means of which it is hoped to be able to determine a constant maximum pour-point.

The author also wishes to stress the importance for the marine engineer of such questions as:

(i) The breaking of emulsions
(ii) The content in explosive vapors
(iii) The asphalt content, etc.

It is also desired to touch upon some special problems regarding the use of boiler fuels in certain gas turbines and in low speed Diesel main engines.

In looking back over the years preceding the Second World War, it can easily be seen how certain characteristics of fuel oils have changed in the meantime. These changes may be said

TABLE 1

Principal characteristics			Vessels				
			BASQUE at sea 1931	*FANTASQUE* at sea 1935	*MELPOMENE* at sea 1936	*MOGADOR* at sea 1938	*FIER* building 1939
Total heating surface in square meters			930	1,390	725	1,028	530
Horsepower			11,000	18,500	11,000	23,000	14,000
Consumption in kg. per hr.	Max. continuous rating	Per sq. m. of total surface	5,860	590	435	79	1,068
		Per cu. m. of room	145	176	194	230	296
	Max. intermittent rating	Per sq. m. of total surface	6,810	65	478	973	1,181
		Per cu. m. of furnace	170	194	212	282	328

to be the outcome of attempts to effect a balance or compromise between the increasingly exacting requirements of modern boilers and a quality of fuel which, by reason of present day refining practice, is steadily deteriorating. Two tendencies, which are at least divergent, if not actually conflicting, are clearly evident. On the one hand, it must be considered that each new boiler design results in a further improvement in performance, as will be seen from the figures given in Table 1. At the same time, these improvements are accompanied by an increase in gas temperature and gas velocity in the various parts of the boiler; and in addition the refractory lining has likewise become subject to higher furnace temperatures. Under these increasingly severe working conditions, the use of certain fuels has led at times to the destruction of the brickwork owing to excessive furnace temperatures, and to the slagging-up of the boiler convection surfaces.

Since the causes of these difficulties have not always been clearly discerned, attempts to deal with the problem have resulted in the insertion of rigid limits in specifications with regard to the content of sulphur, asphalt, ash, etc., which were held to be responsible for such troubles.

On the other hand, there is the fact that the Middle East with its asphalt-paraffin base fuels of high sulphur content, has largely superseded North and Central America as a source of supply of fuel oils to the countries of Europe. In the case of France, for example, it is estimated that in 1951 she will receive 85 percent of her fuel oil imports from the Middle East, as compared with 45 percent in 1938. This situation has perforce resulted in a tendency to increase the maximum sulphur content, which is of course an opposing tendency to that previously mentioned, to limit impurities. The trend towards the employment of fuels with higher sulphur content than hitherto used is all the more marked on account of the increased importance of light and medium distillates, particularly gasoline and gas oils, which is due to the ever increasing demands of industry and of all kinds of shipping. As a brief illustration of the rise in sulphur content, which is today as high as 3.5 percent (F.F.O. Specification), it will be recollected that it was 3 percent before 1939, and 2 percent in 1934 and in fact it was as low as 0.5 percent just after the First World War, if this is not to go too far back.

Furthermore, the parafinic nature of the Middle Eastern fuels is also responsible for the difficulties which are being experienced in the pumping of oils at low temperatures. Also, modern refining techniques introduced in cracking

practice are in their turn bringing into play new characteristics such as the degree of explosibility, or are revealing new aspects of—and also re-emphasizing—such old problems as stability, compatibility, de-emulsification, etc.

Thus the situation is that the requirements of modern boilers for fuels as free as possible from impurities are difficult to satisfy in view of the fact that the interests of economic production lie in a reverse direction. The summary just given furnishes the general background to the problem of drawing up limiting specifications for fuel oils to meet present-day conditions; and the aim of this paper is to review those characteristics which are at present being actively investigated. The point of view of the paper will be that of the user—that is, of the marine engineer responsible for the operation and maintenance of the propulsion plant of a vessel.

SULPHUR

It will be appreciated readily that the progressive raising of the sulphur content in new specifications has given rise to much criticism and to a good deal of anxiety.

In the first place the troubles envisaged are of two kinds:

(1) Corrosion of the boiler drums, of the boiler tubes, and also of the platework.

(2) The harmful effects of the sulphur fumes on the health of the operating personnel. Experience has proved that in a limited number of applications this latter problem is ultimately the more important.

Sulphur in fuel has often been defined as existing in two forms—namely, inert sulphur and active sulphur. The sulphur occurs in many series of compounds the chemistry of which is quite a complicated study. Attempts are sometimes made to assess the extent to which active sulphur compounds are present in the fuel before use, by examining the discoloration of a copper plate immersed in the fuel. However, from a combustion point of view it is the total amount of sulphur which is important. Regardless of the form in which it is present, combustion of sulphur produces sulphur dioxide (SO_2) and a certain amount of the more chemically active sulphur trioxide (SO_3). Various factors, such as the catalytic action of oxide surfaces, are liable to assist the conversion of SO_2 to SO_3.

There is therefore no real reason to attempt to distinguish the different forms of sulphur in a fuel, when the relevant problem is to discover by experiment the maximum sulphur content permissible for any given purpose.

To determine this point, the French Navy has carried out a number of tests, the most recent of which took place in the spring of 1948. As the author took part in these tests, the conclusions then reached will be stated briefly.

For the purposes of this last test, one of the boilers of a cruiser was fired with a Heavy Fuel Oil No. 1, of Middle Eastern origin. This fuel had the following basic characteristics:

Specific gravity	0.955.
Mineral acidity	0
Viscosity	105 centistokes at 50 deg. C.
Sulphur	3.5 percent
Asphalt	6.04 percent
Sulphated ash	0.020 percent
Alkaline sulphated ash content	0.010 percent

TABLE 2

Constituents	1	2	3	4	5	6
Water, percent	7.6	8.2	10.2	7.8	8.6	7.8
Smoke black (tarry carbon matter)	24.6	38.2	34.8	47.4	35.9	37.3
Silicate, percent	1.4	4.3	4.1	2.5	0.3	0.6
Iron as $Fe_2 O_3$, percent	25.2	30.6	18.7	10.8	24.4	29.0
Aluminum as $Al_2 O_3$, percent	0.3	Traces	Traces	Traces	Traces	Traces
Calcium CaO_3, percent	0.3	0.8	0	0	0	0
Sulphates as SO_3, percent	25.7	14.7	27.7	19.9	26.1	20.4
Vanadium as Va, percent	1.9	0.6	1.5	1.2	1.8	1.8
Chlorides	0	0	0	0	0	0
Phosphates	0	0	0	0	0	0
Carbonates	0	0	0	0	0	0

The boiler under trial was of the type brought into service in 1939, design pressure of 27 kg. per sq. cm. for superheated steam operation. It had previously been cleaned and fitted with test specimens of mild steel and copper which were placed in the tube bundles.

The test lasted for 125 hours, during which 282 tons of fuel were consumed. The other boilers in the ship were fired with the normal grade of fuel hitherto used which had a sulphur content not exceeding one percent. The conclusions drawn from the results of this trial refer in the first place to the material, and may be summarized as follows:

Lighting up: No trouble.

Brickwork: The brickwork of the boiler under test showed no particular evidence of deterioration. It was in the same condition as that of the other boilers.

Deposit on Boiler Tubes: The external dirt and deposit of soot on the nests of boiler tubes were not appreciably greater than those found with the use of the usual grade of fuel.

Nature of Soot Deposits: Four samples (Nos. 1, 2, 3, 4) were taken from the boiler under trial, and two (Nos. 5 and 6) from a boiler burning the usual grade of fuel. The analysis of these samples, which is given in Table 2, emphasizes a phenomenon which gave rise to some surprise at first. The soot from the boiler under test was quite comparable to that from the boiler burning ordinary fuel, and it was especially noted that the sulphate content was the same.

It must be concluded from these results that the sulphate content of the ashes does not depend upon the sulphur content of the fuel—in fact, there will always be an excess of sulphur—but upon the elements, particularly sodium, which enter into combination with the sulphur in the furnace. The sodium may be present in the fuel itself, but is more likely to be introduced accidentally owing to the contamination of the fuel oil with sea water. It should be noted that the iron content is much the same in all samples. No special wastage can be attributed to the effects of the greater sulphur content of the new fuel employed.

Visible Corrosion: No fresh or abnormal corrosion was observed either in the tube banks or in the gas passages of the boiler.

Examination of the Test Specimens: Upon being examined and weighed, the test specimens were found to have become browned, although they still retained their polish; also, they showed no sign of pitting or corrosion. So far, therefore, as the material is concerned, the evidence is not unfavorable to the employment of fuels with a sulphur content of up to 3.5 percent.

In dealing, however, with the physiological effects of the use of fuel with this degree of sulphur content, certain disadvantages present themselves. The chief effects noted in this connection may be stated briefly as follows.

On the Bridge: With a following wind, it was found that the smell of sulphur was very marked. Both respira-

tory organs and eyes were apt to become irritated. With other wind directions, however, these effects were less marked.

On Deck: The sulphur fumes were noticed only when lighting up, and at slow speed with no wind, and at moderate speeds with a following wind. There was only slight irritation of the respiratory tract, and no ill effects were observed from this.

Engine and Boiler Rooms: The sulphur fumes were perceptible as on deck, and likewise with no apparent ill effects.

One particular point, however, must be noted. On board the cruiser under test, the galleys were burning boiler fuel. Here it was found impossible to use the fuel of higher sulphur content, because of the considerable discomfort suffered by the personnel when the sulphur fumes pervaded the overheated atmosphere of these small compartments.

To sum up, the results obtained during the course of this test confirmed previous opinions—that is, that with respect to the material, a sulphur content of up to 3.5 percent could be tolerated without serious inconvenience. Beyond this limit, however, as the French Navy has been able to verify on several occasions, rapid deterioration of the platework takes place.

It is a fact that some of the boilers in refineries have used sulphuric tars without excessive attacks on the platework. But these boilers were under continuous operation, and the discharge of flue gas took place at a temperature higher than the dew point of sulphuric acid (175 deg. C.). The working conditions for marine boilers are very different. The intermittent shutting down of the furnaces assists condensation of active agents such as SO_4, H_2, and SO_3 in solution.

Consideration of these factors, together with those relating to the physiological effects of sulphurous and sulphuric gases, can confirm the conclusion that a sulphur content of 3.5 percent must remain a maximum for the present.

ASHES AND SEA WATER

For a long time the specifications for furnace fuel oils have omitted any mention of ash content. Some deterioration of the brickwork, such as washing away of the refractory, must be attributed to the action of sodium, the chemical reaction proceeding according to:

$$Al_2O_3 + H_2O + Na_2SO_4 = Al_2O_3, Na_2O + H_2SO_4$$

The alumina, which forms at these relatively low temperatures of about 900 deg. C. has fluid properties resembling those of glass; and the reaction proceeds continually as new surface becomes exposed. The magnitude of the phenomenon will be clearly evident if it is considered that the alumina forms about one-third of the substance of the fire clay, and that about two-thirds of the ash from the fuel is made up of sulphate of soda. It will thus be seen that under these conditions, an ash content of 1 part per 1000 corresponds to a wastage of 1500 kilograms of brickwork per ton of fuel consumed.

The chief cause of sodium in the fuel is the accidental introduction of sea water into the fuel tanks. The role played by sea water was suspected before the last war, and it is now well established that the greater part of the sodium introduced into the furnace of a boiler results from the fact that an emulsion of salt water and fuel has been burnt. The paper read on this subject by Gray and Kilner* describes these consequences very clearly.

* 1948. Trans.I.Mar.E., Vol. 60, p. 43. "Sea Water Contamination of Boiler Fuel Oil and Its Effects."

Nevertheless, it would be unwise to neglect an additional source of sodium—that is, the sodium content of the fuel itself. It should be remembered that crude petroleum is never entirely free from water, and that the salts contained in the water remain in the oil after distillation. Moreover, during the refining process, the refiners sometimes add not only lime (which is less harmful, although it forms sulphate of lime which can be removed only by mechanical cleaning) but also sodium to prevent corrosion due to sulphur and naphthenic acid. There may, therefore, be solid crystallized salts in the residue which constitutes the fuel; and this in addition to the salts from the sea water. Consequently, it would appear necessary to impose a limit on ash content of Navy fuel, and a maximum of 0.1 percent (1 part per 1000) would seem reasonable.

To illustrate this point, it will be observed that an ash content of 0.1 per cent, of which it is assumed that two-thirds of its weight is formed by sulphate of sodium, corresponds per ton of fuel consumed, to the introduction into the furnace of a mass of alkaline metal approximately equal to that contained in 20 liters of sea water, which is a considerable quantity.

If the action of the sodium were limited to its attack on the fireclay, it could probably be neutralized by the use of a better and more resistant material. But unfortunately, as Gray and Kilner have shown in their aforementioned paper, sodium is also the cause of the formation of deposit on the boiler tubes.

As an instance of the rapid scaling-up of the boiler tubes as a result of using contaminated fuel, difficulties experienced in a large French warship can be cited, although the particular circumstances of this case would make it difficult to determine whether the contamination was due to the presence of sea water or to the introduction of sodium in the process of refining. However it was, the steaming capacity of the boiler became steadily reduced, and very soon the personnel were obliged to carry out most difficult cleaning operations.

The troubles experienced in this particular case occurred in 1945-1946, and reference to them is made because a very simple and effective solution has since been found. It is in fact, sufficient to install an arrangement for spraying the tubes. The deposit, which is primarily composed (as has already been stated and shown by numerous analyses) of soluble sulphates, is by this means easily removed.

The necessity remains, nevertheless, to avoid the introduction of sodium into the boiler. The engineers in charge of the ship's propulsion plant should be able to control the sea water content of the fuel. This emphasizes the need for the provision of measuring instruments designed for shipboard use, such as those which use the entrainment of water by petrol vapor of the British Admiralty pattern.

It should not be relied upon to recognize the presence of a dangerous quantity of water in the fuel by the visual appearance of the flame. For example, another large warship was found to have consumed an emulsion of 10 percent sea water without the boiler-room staff realizing the fact for some time.

The French Navy allows a maximum water content of 2 percent, and this must be checked whenever a change-over is made from one fuel to another.

In connection with this question of limiting the water content in fuels, there should be some mention of the efforts which have been made to rid fuel oil of all emulsified water which it might accidentally contain. The various risks of fuel contamination by sea water may be summed up as follows:

(*a*) Sea water ballast which always leaves traces of sea water at the

bottom of the tank or in some parts of the piping.

(*b*) Leaks in the seams of the tanks.

(*c*) The introduction of damp air as the fuel is consumed.

(*d*) Sea entering the ventilating shafts in rough weather, etc.

The agitation which takes place during rolling and pitching may result in the formation of an emulsion, which, if the troubles previously mentioned are to be avoided, must be broken up or removed before the fuel is used. The author must confess that, for the present, it would appear that this is the only practical course to pursue. Therefore, if an emulsion takes place accidentally, some means must be found to break it.

The physical characteristics of fuel which assist separation are:

(*a*) A low specific gravity.

(*b*) A low viscosity.

(*c*) A natural tendency to de-emulsification.

These are factors which cannot be taken into consideration when drawing up a specification.

With regard to specific gravity, too low a limit must not be set for this, as otherwise it would not be possible to purchase certain heavy fuels such as those from Trinidad. As to the viscosity, this is determined by other considerations, such as the rate of flow when oiling ship. Thanks to tank heating arrangements, viscosity can be controlled to some extent by the engine-room staff.

With respect to a test for de-emulsification, any attempt in this direction would seem to have little chance of success in the case of many fuels, particularly those derived from cracking. It is, therefore, necessary to provide some means of breaking up the emulsions.

Considerable help toward the solution of this problem has been provided by the work of Lawrence and Kilner* which records interesting results obtained by the use of "Teepol." The surface-active properties of this product explain its action. It reduces the surface tension of the aqueous solution and consequently of the interfacial tension between the Teepol-treated fuel and water. Here then is a simple means of separating the water. Moreover, there are a number of other surface-active agents which act in the same way and which can be made easily available.

As a matter of interest, mention can be made of the laboratory experiments carried out with forty-one different commercial products, which have given surface tensions varying from 46.8 dynes per cm. to 22.7 dynes per cm. Their effectiveness can be appreciated if it is remembered that the tension of pure distilled water is 73 dynes per cm. and that of a solution of Marseilles soap is 21.4 dynes per cm. It is believed that the use of these products ashore, assisted by a temperature sufficiently high to help the globules of water to settle by decreasing the fuel viscosity, should give results.

Experiments carried out at the Naval fuel stores to find a method suitable for the breaking up of emulsions on an industrial scale by the application of a commercial surface-active product (Sinnopon) have, after considerable efforts, been crowned with success.

It should, however, be noted that the drop in interfacial tension between the two phases fuel and water reduces the energy necessary to the formation of an emulsion, and that a fairly gentle agitation will produce dispersion—that is, a result opposite to that aimed at. This fact would seem to prohibit the use of this method on board a ship at sea.

* Jl.Inst.Petroleum, 1948, Vol. 34, p. 821. "Emulsions of Sea Water in Admiralty Fuel Oil with special reference to their Demulsification."

Another source of anxiety, which is connected with the previous one, arises from the observation that the interfacial tension between a fuel and a solution seems to be little affected by the amount of surface-active agent contained in the latter. It would seem that a stable interfacial tension is attained from the moment when a very thin layer, perhaps even only a single molecule in thickness, is adsorbed at the interface. This layer would, of course, be produced from very low concentrations.

Thus it might happen that in a tank which had previously contained an emulsion which had been treated with an emulsifying agent, there might remain enough of the active product which, after dilution with a new fuel charge, would still be effective to assist the formation of an emulsion in the event of admission of water or sufficient motion of the ship. The problem of the breaking up of an emulsion on board ship is therefore not yet entirely solved. In fact, it is even probable that there is no single general solution. The various emulsions differ from one another according to the nature of the disperse phase which may be fuel or may be water (as is generally the case with emulsions on board ship), and their stabilization is due to a variety of causes. They are more or less assimilable in colloidal suspensions, and it is certain that the various means in use to produce flocculation of such suspensions will all have to be brought into play according to the case and the result aimed at.

BEHAVIOR OF FUELS AT LOW TEMPERATURE

For some years past, and since fuels from the Middle East have come into more general use, difficulties have been experienced in the employment of fuels at low temperatures. Shore installations have been brought to a standstill owing to the impossibility of pumping the fuel. The same troubles have been experienced on board merchant ships in cold waters. This was not so much due to an exceptionally low ambient temperature, but to the fact that the paraffin base fuels of the Middle East are most unfavorably affected by cold.

One can for discussion purposes classify petroleum fuels into:

(*a*) those of naphthenic or asphaltic base,

(*b*) those of mixed asphaltic-paraffin base.

Such a division is not, however, very accurate.

The variation in viscosity of the former with the temperature follows Walther's law fairly closely, which is to say, a straight line relationship obtains in a diagram in which the logarithm of the temperature is plotted against the log-log of a linear function of the viscosity.

The divergences which have been observed in viscosity determination according to whether the measurement is carried out with increasing or decreasing temperature are too small to be of any decisive importance. The viscosity naturally increases with the cold, but the fuel remains fairly fluid until it reaches a certain low temperature because it does not contain any solid constituents. But after passing a certain temperature, known as the "pour point," it loses its fluid properties. The important factor is that for an asphaltic fuel, this pour point is practically independent of the manner at which it is determined. It is almost constant. At higher temperatures, the fuel is fluid, and its viscosity is given sufficiently accurately by the viscosity-temperature curve.

This is not the case with Middle Eastern fuels, for which it is difficult to define a viscosity below 50 deg. C. For some fuels there is even an actual "drop point" above 50 deg. C. It is only

at a temperature above 50 deg. C. that, as the wax is dissolved, the fuel behaves in the manner indicated by Walther's law.

At temperatures below 50 deg. C., the paraffin crystallizes and the structure, influenced by the very variable state of the crystallization arising from the circumstances existing at the time, is no longer constant. The fuel is no longer viscous and Walther's law therefore does not apply. To illustrate the great variation in viscosity below 50 deg. C. for this type of fuel, an instance may be given of a sample which had a viscosity below 50 centistokes at 50 deg. C. and for this reason might have been classed among the light fuels, whereas in fact it was solid at 45 deg. C.

That is why, in order to determine a fixed datum point, the specification of F.F.O. (furnace fuel oil) lays down the limiting viscosity at 50 deg. C.

The crystallization of paraffin is responsible for yet another phenomenon which has serious consequences. With the inconstancy of the pour point, there are certain fuels for which the variation of the congealing point between the port of embarkation in the Persian Gulf and the port of discharge in Europe varies as much as 20 to 25 deg. C. Little need be said to emphasize the danger which a ship would run in using such a fuel which, having been embarked on the understanding of a satisfactory pour point, would be found to have become solidified in the tanks a few weeks later.

It is said that the congealing point depends upon the previous thermal or mechanical history of the fuel. Now this influence of the history of the fuel can be better explained by noting that the variability of the pour point seems to be affected by simultaneous presence of paraffinic and asphaltic matter. These latter act somewhat in the manner of a "pour point depressant" used for lowering the congealing point of certain lubricating oils. While cooling, the asphaltic matter which comes out of solution, is deposited on the nascent paraffin crystals in course of formation, thus isolating them from the "nutritive" matrix, arresting their development, and so causing a formation of small crystals which forms a rigid structure only at fairly low temperature, or for a more lengthy period of contact. Without asphalt, a rigid structure of large crystals would have formed quickly at a higher temperature. The action of the asphalt is, therefore, to lower the pour point. Unfortunately, this action is but temporary, and, as it were, the paraffin crystals free themselves in the course of time from their asphalt envelope to build up a system of large crystals which they would have formed at once if no asphalt had been present.

The interpretation of facts assists the understanding of the principle of certain methods which are carried out in the laboratory in order to determine a pour point which would avoid for the user any "surprise," and which could be called the "true pour point." The aim of such a method would be to determine the temperature above which the fuel would always remain fluid, and below which it would certainly solidify sooner or later even if its thermal or mechanical history allowed it to remain temporarily fluid.

Certain authors ("Cold Test for Fuels," by Moerbeek and A. C. Van Beest) have shown that it is sufficient to apply the A.S.T.M. method to fuel freed from asphalt, either by the action of sulphuric acid or by selective extraction by a solvent. The same result might be obtained by a technique employing purely physical means. The method of heating up to 100 deg. C. has been recommended, whereby the asphalt and paraffin would be entirely dissolved. All influence of prior history would thus be removed. This would be followed by a cooling to 0 deg. C. in order to crystallize the wax and precipitate the asphalt.

The product would then be reheated to about 35 deg. C. to 45 deg. C., which would once more dissolve the wax, whereas the precipitated asphalt would remain undissolved and, therefore, would have no more influence than any other sediment. In this condition it would be possible to determine the "true" congealing point of the fuel. The matter is being studied in the Naval Laboratory in order to obtain by various tests confirmation of the exactitude of these views.

It is unnecessary to emphasize the importance of the development of a practical method to determine the maximum jelling point temperature. If such a method were to be perfected, it would be possible to establish a limit to the true pour point for the Naval fuel, so that both technical requirements and financial considerations could be satisfied.

Once the uncertainty with respect to the real value of the pour point has been cleared up, the primary consideration will be to establish the temperature at which the fuel can be carried in the tanks. For reasons of health and safety it is estimated that this temperature should not be above 30 deg. C. Fuels which have a "true pour point" considerably below this could therefore be used. The principles governing the use of fuels can be stated as follows:

Heating is carried out in two stages.

The tanks are fitted with coils which ensure a uniform heating effect which liquefies the fuel so as to enable it to enter the suction intake of the pump.

The heating coils are placed as low as possible so as to reduce the volume of unpumpable fuel as completely as local arrangements permit in order to avoid what has been called the "Igloo effect" (or rat-hole), i.e., the formation of a cavity left by the melted fuel which has been drawn away by the pump.

The general heating system must be capable of raising the temperature of all the fuel to 30 deg. C. even under the most severe temperature conditions, which in Europe has been fixed as 1 deg. C. for sea water and 8 deg. C. for the atmosphere.

The heating of waxy fuels once they have congealed is difficult, since the convection of heat throughout the solid mass cannot take place, and progressive melting by thermal conduction is a very slow process. The heating of the tank to 30 deg. C. will thus be slow, and it may take as long as 6 hours for the boiler room tanks and 24 hours for the reserve tanks. In this connection it must be kept in mind that the temperature of the heating surface must not be too high, in order to prevent excessive "coking" of the fuel where it is in contact with the heating coils, which, if allowed to occur, would call for unduly frequent cleaning.

Final heating is carried out by a heating coil surrounding the suction pipe. Its purpose is to raise the fuel which has become fluid to a temperature which will ensure a maximum viscosity consistent with boiler operation at full power. This viscosity is about 600 centistokes.

The use of paraffinic fuels also requires the heating of the suction pipe between pump and fuel tank.

Arrangements must also be made for lighting up the boilers from cold. Steam for heating the fuel may be obtained from a neighboring ship or from a lighter; or heating may be carried out electrically with electric current provided by the auxiliary generator plant of the vessel, or from some outside source. But arrangements of this kind are costly and heavy, and they also reduce efficiency and complicate operation.

Failing sufficient viscosity-breaking equipment, this is the price, however, that must be paid if one is not to limit

oneself to those fuels from the Middle East which, after a long storage at about 0 deg. C. still possess a viscosity lower than 600 centistokes. Such fuels contain a large proportion of gas oil which should not be fired under boilers, but should be reserved for use in Diesel engines; otherwise both industry and shipping are likely to suffer from shortages of Diesel fuel.

STABILITY AND COMPATIBILITY OF FUELS

Reference has been made to the "coking" of fuels in contact with heating coils. This matter is linked up with the more general question of the stability of fuels and their mutual compatibility.

As understood by the user, a stable fuel is one where flocculation does not occur nor are asphaltic deposits produced in storage or under service conditions. Compatibility of a fuel is its capability to form stable mixtures with other fuels.

Experience has proved that not all fuels are stable, nor are all compatible with each other. Ships have in fact found themselves in difficulties after using mixed fuels from different sources. Piping and heating coils have been found blocked, and this has necessitated the shutting down of boilers and the carrying out of difficult cleaning operations. These troubles have occurred when the products of cracking—and particularly of thermal cracking—have been used.

The explanation of these facts lies in the very nature of fuels. Fuels are composed of residues, of very complex mixtures of hydrocarbons belonging to all the series, some of them of very high molecular weight. To these must be added, although only in small quantities, asphaltic products containing oxygen, sulphur, and sometimes nitrogen. The different series of hydrocarbons, with their various members, exist in very variable proportions according to the origin of the crude oil and to the treatment it has received. In certain cases the mixture proves stable thanks to a mutual solution of the constituents. Similar compounds of a series are soluble in the neighboring compounds of a series. Like dissolves like.

All series of hydrocarbons, however, have not the same solvent power, especially where it is a matter of solubility between different hydrocarbon series. In this connection, certain definite qualities emerge. Aromatic hydrocarbons are excellent solvents, whereas saturated hydrocarbon compounds are much less so. Ordinary petrol precipitates asphalts, benzine dissolves them. The mixture which goes to make up a fuel may still appear stable, because of a dispersion of colloidal nature, containing large insoluble molecules, microcrystals of paraffin, etc.

The equilibrium of the colloidal system is assisted by the presence of certain peptizing compounds such as anthracenic oils distilled from coal, tars, and aromatics obtained from solvent refining operations. Viscosity is also a factor affecting equilibrium. The basis of the reasons which have been given to explain instability derives from very important experimental findings.

Fuels from cracking as they come from the still, are stable. Left to themselves, they leave no deposit when heated to temperatures of 80 to 100 deg. C. The same applies to fractionated fuels, but mixing them frequently results in flocculation. This leads to the conclusion that in cracking operations, as in straight distillates, the different constituents are present in such proportions that an equilibrium is attained from

the mutual solubility of the various constituents, a gradual peptization taking place of the heavier compounds by the neighboring lighter ones, from the higher members to the lowest of a hydrocarbon series. Similarly, solution and peptization of the heavy constituents by solvents and dispersants, to which reference has already been made, may occur, with aromatics, for example, as well as with naphthenes. Stability results from a certain harmony in the relative proportions of the constituents.

The mixture of two stable fuels by altering the mutual concentrations, alters the equilibrium of the solutions and of the suspensions, and leads to a breakdown, so that the fuel flocculates. This point of view is entirely confirmed by the work of Butlin.* It provides a means of evaluating one of the characteristic elements of stability. It refers, it is true, to the compatibility between fuels and gas oils, but the principles upon which it is founded are, in the author's opinion, also valid for mixtures of fuels.

With any given fuel it can be determined experimentally with which diluent—white spirit—(without aromatics) with the addition of n percent of xylene —it can be mixed, in the volumetric proportions of 1 to 5 without flocculation.

The smallest value for n constitutes the "xylene equivalent" of fuel. This may be regarded as a measure of the tendency of fuel to flocculate. The expression 100-n would, on the contrary, be a measure of its stability. It would therefore seem possible to find the relationship which must exist between the "xylene equivalents" of two fuels in order that they should be compatible, or else the maximum "xylene equivalent," in order that the fuel should be stable for Naval purposes.

An investigation into this matter is now taking place in the French Fuel Testing Station.

But if the users have not as yet attained a standardized laboratory method of control for stability, they have for a long time been taking precautionary measures. Thus it is that the French Naval Specification of 1st March, 1937, laid down:

"That F.F.O. (furnace fuel oil) must show no tendency to form sediment between temperatures of 0 deg. C. to 40 deg. C."

"F.F.O. should not show any tendency to form excessive sediment in the heaters when being raised to a temperature corresponding to 30 centistokes."

It should be noted that here 30 centistokes is the viscosity of the fuel taken at the burners.

Control was effected by means of a centrifuge with a mixture of equal parts of fuel and of a fluid paraffin oil (with zero iodine value). The mixture was first raised to 100 deg. C. and the amount of sediment gave a conventional classification of the fuel. In case there was some technical difficulty, a supplementary stability test was also allowed for. The fuel was heated for 24 hours at 140 deg. C. and then placed in a centrifuge together with an equal volume of benzine at an approximate temperature of 50 deg. C. The amount of sediment was also measured in this case.

Since the last war, the French Navy has ceased to use these methods in favor of the N.B.T.L. test given in the specification of the American Navy. This test is universally known, and reproduces fairly well the temperature conditions to which the fuel is subjected in practice on board ship. The test actually consists of the formation of a closed circuit for 20 hours of a certain quan-

* Jl.Inst.Petroleum, 1950, Vol. 36, p. 43. "Stability of Fuel/Gas Oil Blends."

tity of fuel around a heater tube in such a way that the temperature of the fuel is maintained at 93 deg. C. At the end of the test the deposits on the tube are examined. In order to arrive at a better appreciation of them, about 20 cm. of the tube is washed with benzine, after which half this section is cleaned by hand with a clean soft rag. The tube is then subdivided into three lengths:

(i) Neither washed nor wiped.
(ii) Washed but not wiped.
(iii) Washed and wiped.

To quote the specification: "A stable fuel is characterized by the presence of a simple film of fuel on the first length, and a discoloration or negligible amount of film on the second length."

It is obvious that the third length, would show a bright metal surface, with no discoloration.

It is not enough, however, to ensure the stability of the fuel. It is also necessary to prevent a heavy flocculation after oiling ship at any port where the ship may call. It is furthermore necessary to control the compatibility of the fuel which has been taken in with the fuel which is already in the tanks. Yet it is obviously impossible to test each fuel with every other fuel which may be encountered. Two reference fuels, therefore have been selected, which are considered to be at opposite limits of the possible range. These are:

One is of a paraffin base obtained by distillation. This is the Middle East type of fuel.

The other is a mixture of fuels derived from cracking, such as the fuels produced on the West Coast of the U.S.A.

It may be assumed that the fuel under consideration will be compatible with any other Navy fuel provided that it is separately stable at the N.B.T.L. test when mixed in equal parts with each of the reference fuels.

The N.B.T.L. test, while empirical, has much to commend it, but it cannot be determined on board ship. If it were possible to produce a test as simple as the xylene equivalent and relate this to practical questions of stability and compatibility, the Navy's problems would be greatly eased.

EXPLOSIVE VAPOR CONTENT

Before the last war, the French Specification did not concern itself with the content of gaseous hydrocarbons dissolved in the fuel, but the present specification fixes an upper limit, as in the American Navy Special. Evidently, as is still the case, a minimum flash point was laid down; but the object of this is to limit the amount of light products, both liquid and gaseous. It is only with some difficulty that the presence of these products in dangerous proportions can be discerned when making tests with the Luchaire or Pensky-Martens apparatus.

Some modern cracking processes are inclined to leave in the fuel oil a certain amount of lighter hydrocarbons, an excessive quantity of which could be dangerous. During storage, specially in tanks on board ship, these dissolved gases are slowly liberated and the confined atmosphere above the fuel may become explosive. Their presence may also be dangerous when the burners are being lit. The presence of such dissolved light hydrocarbons can be checked by shaking at 52 deg. C. in a half-filled container. The air in the container becomes filled with volatile constituents, and the content of explosive vapors is measured by the use of a properly graduated explosimeter. The explosibility indicated should be less than half the lower limit of explosibility of natural gas.

ASPHALT

There is a tendency in modern specifications to ignore the asphaltic content of fuel. But even if the influence of asphaltic compounds is neither so marked nor so deleterious as that of sodium or sulphur, its technical aspect should not be overlooked.

For its complete combustion, asphalt requires a fairly high temperature and as fine a pulverization as possible. As soon as the asphalt content gets above 10 percent, heating and pulverization are insufficient to ensure proper combustion; and small dry pellets are formed in the furnace. Their formation is due to the fact that droplets of a fuel containing asphalt burn only on the surface, leaving a core of unburnt combustible.

HEAVY FUELS AND GAS TURBINES

The French Navy has not so far had any experience with gas turbines used for propulsion. It possesses, however, some "Sural" boilers for which the combustion air is provided by turbo-compressors which are driven by gas turbines supplied with the furnace gases from the boilers.

Here again the presence of sodium has caused a certain amount of trouble. The gases, on entering the blades, are still very hot (above 500 deg. C.), and sometimes alkaline sulphate in the form of paste, drawn in by the current of gas, is deposited on the blades, thus bringing about accumulations of deposits.

When making an inspection of these boiler turbo-blowers, the following observations were made concerning the origin of the deposits.

(1) The dirt is particularly heavy at the inlet. The deposit formed is compact and flakes off easily.

(2) The stationary blades are very rough even on the side where the gas leaves. On the back of the blades the deposit was 3 to 4 mm. thick, probably owing to the reduced speed of the gas.

(3) The deposit on the moving blades is less heavy. It is found principally near the blade tips, due to centrifugal action, and on the back of the blades at the inlet side.

The deposit is of the same kind as that found in boilers, but more compact, harder, and more adhesive, particularly where it has accumulated by centrifugal force on the outside root of the blade where it is removed only with some difficulty when dry. But removal of the deposit when wet can be effected easily. This is done by soaking it for several hours in softened water, after which it can be washed off with a hose.

Chemical analysis has shown that the magnitude of the deposits is not due to accidental incomplete combustion leaving a small amount of unburnt carbon; neither is it related to the ash content; but it increases rapidly with the sea water content of the fuel. The deposit which takes place fairly slowly at first after cleaning, increases more rapidly when it has reached a certain thickness, and also when the boiler and superheater tubes on the inlet side of the gas current become soiled.

This can be explained quite easily by the fact that the deposit remains in the form of solid particles, agglomerated but not viscous, so long as their temperature remains below 550 deg. C. In this condition the impurities brought in by the gas cannot be retained; but as soon as the boiler and superheater tubes reach a certain degree of dirtiness, heat absorption diminishes and hotter gas

therefore enters the turbine. When a temperature of 550 deg. C. is reached, the pasty consistency of the alkaline sulphate helps to bring about agglomeration of all the solid waste carried along with the flue gases.

The growth in thickness of the deposit in time may be represented by Fig. 1.

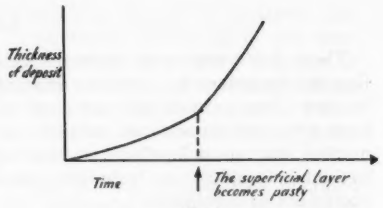

FIG 1.

Mention has been made of the destructive action of vanadium which is formed in various residual fuels in appreciable amounts up to about 0.05 percent, more especially in heavy fuels from Venezuela and Iraq. This is a dangerous element, and is a veritable poison for steels which have a high molybdenum content, and which have to withstand high temperatures.

As the author has no personal experience in this connection, he cannot give first hand information on these matters. But it is well-known that in refineries vanadium has attacked the tubular supports of "still-pipes" made of molybdenum steel to a point where they have disappeared completely. When gas turbines enter regular service, this point will have to be considered in the specification.

BOILER FUELS IN DIESEL ENGINES

For several years, a number of successful attempts have been made to use heavy boiler fuels for marine Diesel engines. So far such attempts have been confined to large main engines running at relatively low speeds, such as 120 rpm.

Some time before the last war, Burmeister and Wain engines fitted in French Naval tankers were run on relatively heavy fuel up to 50 centistokes at 50 deg. C. It was simply specified that such fuel should have the following purity characteristics:

Sulphur content..less than 2 percent
Asphalt content..less than 1.5 percent
Ash content.....less than 0.5 percent

One of the French Shipping Companies (the Compagnie Auxiliaire de Navigation) in similar engines used a fuel of approximately 300 centistokes at 50 deg. C. A report on this subject is given by Monsieur J. Perrachon in the Bulletin of the Association Technique Maritime et Aeronautique, No. 48 of 1949, page 347.

The experiments of the *Auricula** also prove that the use of heavy fuels (1500 sec. at 100 deg. F.) is both possible and economical in Diesel propelling engines. In fact, the author considers that fuels of most varied viscosity and even of varied chemical nature can be used without any difficulty in slow speed internal combustion engines.

During the 1939-45 war, submarine engines of the Sulzer type, for instance, were able to run on ground nut oil, provided that certain precautions were taken regarding the organic acidity of this oil. This fuel had of course characteristics which differed very materially from the ordinary normal gas oil. i.e.:

(*a*) Viscosity at 20 deg. C. was 85 to 90 centistokes instead of 3 to 9.
(*b*) Flash point of 258 deg. C. instead of 75 deg. C.

* Lamb, J. 1950. Trans.I.Mar.E., Vol. 62, p. 217. "Further Developments in the Burning of Boiler Fuels in Marine Diesel Engines."

(*c*) Spontaneous ignition temperature of 400 deg. C. instead of 260-280 deg. C.

(*d*) Heating value of 9560 calories instead of 10,700 calories.

Engines have also been run on a great variety of oils such as palm oil and rapeseed, cotton, sunflower, olive, linseed, maize, and soya oils. This list could no doubt be extended.

With respect to petroleum fuels it is necessary to lay down fairly close specifications if trouble is to be avoided. It will probably be necessary to avoid using such fuels unless the characteristics indicate a fairly high measure of purity.

The reports referred to above draw attention to the need for purifying the fuel. As in the case of boilers, the most injurious elements are sodium and sulphur for the following reasons:

(*a*) Sodium forms sulphates which are deposited on the valves and are responsible for back firing when the hot gases find a passage through this layer of salt.

(*b*) Sulphur produces corrosive sulphur dioxide and trioxide.

The centrifuging of the fuel aboard ship allows the sodium to be got rid of to some extent by extracting the salt water and so eliminating certain solids in suspension. For certain fuels even such means are insufficient, and there is no doubt that recourse will have to be made to washing the fuel with fresh water to remove the chloride and the naphthenate of sodium, as has already been stated. Unfortunately, it is not possible to do this on board ship, nor is it very easy ashore, as there is danger of producing emulsions.

A determination of the ash content will give some idea of the efficacy of the measures taken. It should be possible to get it below 0.05 percent, which would be quite acceptable.

As regards sulphur, the only possible course at present is to fix a maximum content.

Whenever the temperature at any part of the engine which may be contacted by the combustion gases falls below the dew point—that is, somewhere in the region of 175 deg. C.—sulphuric acid condensation with a solution of sulphur dioxide may take place. The temperature in a crank case is obviously much lower.

Diesel motors ashore, however, operate at high temperatures, yet the operating personnel are well acquainted with the amount of wear, dirt, and difficulty of maintenance resulting from the use of gas oil contaminated with sulphur. Even a sulphur content of below 1 percent can have a most injurious effect. It has, in fact, been found necessary to produce special heavy duty lubricating oils, such as Supplement No. 1 and Supplement No. 2, in order to avoid corrosion and other troubles. The high prices of such lubricants are sufficient testimony of the importance placed by the operators on a fuel free from sulphur.

Even if some of the evil consequences of sulphur were to be minimized by the resistance of the material, this element remains nevertheless most injurious to marine engines, and the author considers it essential that a limitation of the sulphur content to 2 percent should be imposed.

From a technical point of view, the high viscosity of fuel oil does not constitute a serious difficulty, as it is only necessary to heat it to a sufficient fluidity for injection. Fortunately there remains a certain margin, and the pulverization is still correct up to about 25 centistokes. If relatively thick vegetable oils such as have been mentioned above, are used, their viscosity still allows satisfactory injection. As compared with gas oil, however, it has been

found necessary to increase the load on the needle springs in the mechanical system from 20 to 50 kg. per sq. cm. For engines with an air-blast injection system, the air pressure has to be increased, from 5 to 10 kg. per sq. cm. It may be noted that a viscosity of 25 centistokes can be obtained at 90 deg. C. with the Grade II type of fuel of the U.S. Navy (300 centistokes at 50 deg. C.), which is not excessive.

Another feature of vegetable oils is their ignition delay. It has been found necessary to advance the injection from 1 to 2 degrees. Such considerations are also valid for heavy petroleum fuels. Incidentally, these fuels possess certain advantages over light fuels, inasmuch as their use results in smoother running and the engine knocks less. The author has noticed this on many occasions with Bermeister and Wain engines.

In conclusion, the author considers that the use of heavy fuels in Diesel engines is dependent on their purity. The principal characteristics of this essential purity are a low ash and a low sulphur content. Adequate arrangements for heating the oil to a suitable viscosity for injection are also necessary. No special technical problem is raised by these requirements.

As regards the question of whether it is financially advantageous to use these products, this can only be decided by drawing up a balance sheet. On the credit side would appear the low price of these fuels, while on the debit side there would be the cost of setting up purifying and heating installations and their amortization. But neither of these factors can be considered as fixed.

With respect to the question of availability of fuels, it is certain that the demand for gas oil and for light fuels will be increasingly difficult to satisfy; so that it would, therefore, be desirable to persuade the makers of Diesel engines to make their equipment more flexible in regard to fuel requirements.

THE EFFECTIVENESS OF THE INACTIVATION PROGRAM

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Following the close of World War II over two thousand vessels of the United States Navy were placed in an inactive status.

This establishment of a "Reserve Fleet," which was obviously dictated by economic reasons, had been planned well in advance of the conclusion of World War II and the efficacy of the concepts developed by the original planners of the Reserve Fleet, has been proven in the expeditious activation of large numbers of these vessels in the past two years; and in the improved material condition of all vessels in the Reserve Fleets after the five to six years that the majority of them have been in an inactive status.

Since the establishment of a Reserve Fleet was dictated by economic reasons, it followed that the costs of maintaining these vessels in a satisfactory material condition and an acceptable state of material readiness, would have to be kept low enough to make the plan feasible. This has been accomplished to a degree probably far beyond the expectations of the originators of this plan. In fact, in view of current world events the Reserve Fleet has undoubtedly proven to be one of the finest investments that could have been made.

The yearly costs of maintaining the vessels in the Reserve Fleet have averaged less than one percent of the original construction costs of these vessels. Furthermore, the funds that have been allocated to the Reserve Fleet have been used not only to maintain the vessels in a satisfactory condition as regards to preservation, but also for the over-all improvement of these vessels.

With regard to material readiness, the current activation program has proven that these vessels can be made ready to

join the active fleets in accordance with the schedules promulgated by the Chief of Naval Operations.

These achievements have been made possible principally by the adaptation of preservation procedures that are most consistent with maintaining the highest state of material readiness. Other factors, such as the quinquennial overhaul program and the various group maintenance projects have also contributed in a large measure to the success of the Reserve Fleets. However, it is considered that the use of dehumidification, that is the control of humidity within the structural boundaries of the vessels, is the most singular reason for the excellent preservation and resultant high material readiness attained.

The principles of dehumidification within Reserve Fleet vessels have previously been reported in this JOURNAL and are quite well known. Briefly, it is the maintenance of the atmosphere within the structural boundaries, at a relative humidity of about 30 percent. Under these humidity conditions corrosion of ferrous materials is entirely arrested and even highly polished ferrous surfaces will remain bright indefinitely. Other materials within the vessels are not adversely affected by the 30 percent relative humidity. Some materials such as wood, fiber gasket materials, and leather parts, suffer a reduction in their normal moisture content. However, in most instances this moisture content is regained when the materials are again exposed to ambient conditions. Maintenance of the dehumidification machines and the sensing apparatus which provides for the automatic control of these machines has proved to be very low in manpower requirements.

An example of the high regard that is held for dehumidification is evidenced by a development that has taken place in the Reserve Fleet, largely on the initiative of the personnel that have been maintaining these vessels. The original instructions for the preservation of gun mounts and various machinery units located topside, called for impervious plastic packages to be built up around these units. However, in time it was found that the maintenance of these plastic packages required excessive manpower. As funds permitted, the plastic packages were gradually replaced by metal huts. These huts were placed in a series arrangement by suitable temporary piping and small dehumidification machines, operating on the same principle as the larger machines used within the hull interior, were then placed in the system. Dehumidification of costly exposed units of machinery and gun mounts was thereby attained with a resultant reduction in maintenance requirements and vastly improved preservation.

The only unsuccessful application of dehumidification took place early in the inactivation program when it was attempted to maintain small wooden hull vessels with the same relative humidity as maintained in the interior of steel hull vessels. It was found that at 30 percent relative humidity the planking suffered abnormal shrinkage and seams opened, permitting seepage of sea water into the vessel. Later in the program an experiment was initiated to maintain certain machinery spaces in these wooden hull vessels at a relative humidity of 50 percent. Although the vessels were activated prior to obtaining conclusive results, the indications were that the machinery units within these vessels could be preserved with controlled humidity conditions of about 50 percent without shrinkage to the hull planking.

Another preservation measure used on Reserve Fleet vessels that has been found to afford excellent protection with high material readiness are coatings known as thin film rust preventive compounds. These compounds are essentially a combination of two major con-

stituents. One, a solvent of the light kerosene type and the other a blend of solids, semi-solids, or wax-like inert materials. Upon application the solvent evaporates leaving a tough protective film of the solid materials. These compounds come in three grades designated as I, II and III. Grade I, the toughest and thickest of the three compounds, is used on corrodable surfaces that are exposed to the weather and that cannot economically be placed under dehumidification such as, standing wire rigging, ferrous life lines, machined ferrous surfaces, etc. Grades II and III are used within dehumidified compartments in locations such as interiors of pipe lines, where dehumidified air does not normally diffuse, and as a secondary protection for corrodable surfaces in the event of failure to the power supply which make the dehumidification machines inoperative. Also, during periods of shipyard overhaul the dehumidification machines are secured, and full reliance for protection of corrodable surfaces is placed on these protective films.

The results attained with grade I thin film rust preventive compound in the preservation of topside fittings, etc., on Reserve Fleet vessels, have been so excellent, that, not only has this compound been adapted for similar usage in active fleet vessels, but also, tests are now underway to determine whether this coating is more durable than the standard paint systems for the protection of topside hull structure.

The preservation methods and procedures prescribed for specific structure, equipment, and machinery, have been under continuous review throughout the entire period of the inactivation program. For instance, the original instructions provided for the drydocking of Reserve Fleet vessels once every five years for the purpose of inspection and renewal of the preservatives applied to the underwater structure and appendages. However, after a period of approximately two and one-half years it was noted that the preservative coatings applied at the waterline areas on a large number of vessels were breaking down and resultant corrosion and pitting of the shell plating in these areas was taking place. In view of this condition a program for the interim preservation of the waterline areas of all light hull vessels berthed in salt water was inaugurated. In most instances, this was accomplished by group personnel by inclining the vessels sufficiently to permit the surface preparation and painting of the waterline area. Also, in connection with drydocking periods, it has been determined that in some berthing areas the drydocking interval can safely be extended to six and perhaps seven or eight years. In other areas it appears that the drydocking interval will have to be shortened to three or four years. Another procedure for the preservation of underwater structure of Reserve Fleet vessels, that is now being thoroughly and actively investigated, is the use of cathodic protection which, if successful, will attain for underwater structure a degree of preservation comparable to that which has been attained for interior structure with dehumidification.

The preservation of topside exposed structure has been, by far, the greatest consumer of manpower in the maintenance of Reserve Fleet vessels. As such, this aspect of preservation has been the recipient of the most attention, insofar as developing ways and means of improvement. This problem has been investigated for surface preparation procedures and protective coating systems. At the outset of the inactivation program standard paint systems in usage at that time were prescribed for exposed structure of Reserve Fleet vessels. With these paint systems, surface preparation to bare metal is a mandatory requirement for durability of the protective coating. This immediately presented a problem with the thousands

upon thousands of square feet of surface that required preparation prior to painting. The start was very slow, with Group personnel using the various hand tools, such as, chipping hammers, scrapers, and wire brushes that were used by ships force on active vessels. It was soon realized, however, that faster and better means would be required if the task was going to be accomplished. Various commercial mechanical surface preparation tools were given trial by Reserve Fleet Personnel. Pneumatic multiple chipping hammers and a tool using multiple rotary cutting blades were found to be an improvement over hand methods and were extensively used. However, even these mechanical tools were found to be too slow and required altogether too many operators for complete surface preparation and painting of topside areas. The methods of surface preparation that are most generally used today, for complete painting of Reserve Fleet vessels, are sandblasting and grit blasting. In most Reserve Fleet groups full scale production blasting is now in progress. Usually, vessels are moved to one designated area within the group and a well trained team of specialists prepares all topside surfaces. In one Group a schedule has been established for the sandblasting of the topside surfaces of three vessels, about the size of destroyer, per week during the periods of the year when this type of work is possible.

With regard to paint systems in use for the preservation of Reserve Fleet vessels, there have been many new developments and promise of more to come. One of the first changes in the painting procedures for Reserve Fleet vessels was the substitution of red lead primer for zinc chromate primer for exposed topside structure. Another system which is an innovation in the Reserve Fleet is the use of a coal tar emulsion on horizontal surfaces of certain types of vessels berthed in very damp climates. Also, a pre-wash primer has been developed which will inhibit corrosion of exposed prepared surfaces for as long as seven days.

A service test of many different types of protective coatings for topside structure is now in progress in the Reserve Fleet. Included in this test is the previously mentioned grade I, thin film rust preventive compound. Also, in these tests, various degrees of surface preparation, ranging from merely loosening and sweeping down large rust scale to the attainment of a bright surface are being tried with various protective coatings. The possibilities of flame de-scaling are also being evaluated in these tests.

With regards to the overall improvement in the material condition of Reserve Fleet vessels there are two noteworthy programs that were established for this purpose. These are the quinquennial overhaul program and the group maintenance programs.

The quinquennial overhaul program was established to provide regular shipyard overhauls each year for one-fifth of the vessels assigned to the Reserve Fleet. Thus, in a five-year period, all vessels in the Reserve Fleet were to receive a regular shipyard overhaul. The work lists were prepared from available records aboard the vessels and from information derived from inspections conducted by group personnel, Board of Inspection and Survey, and other inspection groups. Funds were allocated by the Reserve Fleet Commanders for the overhauls in the same manner as allocations are made by Type Commanders in the active fleets.

In all instances, vessels that received shipyard overhauls under this program were improved as regards to material condition. However, there was one inadequacy that became apparent early in this program. That was, in a large percentage of the vessels, records as to actual machinery conditions were not

complete since, due to the exigencies of war service sufficient attention could not be or was not devoted to the preparation and maintenance of current records. Furthermore, due to the inactive state of the vessels it was not economically feasible to activate units of machinery to determine their actual condition prior to the overhauls. As a result, although all known deficiencies that required shipyard repair were corrected, there were many items not corrected due to the lack of knowledge of their existence.

Also, in some years sufficient funds could not be made available to permit the scheduled shipyard overhauls of these vessels, and the quinquennial program became an intermittent program that was dependent on the availability of funds. As a result, when the activation of certain numbers of vessels was required, not all vessels had received shipyard overhauls, and repairs beyond the capabilities of ship's force and Group personnel had to be accomplished incident to or following the activations at industrial activities.

When it became apparent that due to the lack of funds, the quinquennial shipyard overhaul program could not be carried out each year as originally planned, an ambitious program was initiated for Group personnel to undertake ship overhauls within the extent of the facilities available. The work accomplished by military personnel in these group projects has been outstanding and gave evidence of the fact that the ingenuity of the American sailor of today matches that of the sailor of yesteryear when it comes to devising ways and means for the repair of machinery and equipment. Also, and not surprisingly, the morale of the personnel assigned to the Reserve Fleet received a tremendous lift when those persons were called upon to do extensive repair work.

As previously mentioned, the current activation program has proven that Reserve Fleet vessels can be made ready to join the active fleets in accordance with schedules promulgated by the Chief of Naval Operations. These activations are a complex procedure requiring teamwork and coordination of many and various Naval activities. With considerable forethought, the Navy Department ordered the activations of several vessels from the Reserve Fleet prior to the relatively large activation program that has been in progress for the past two years. These activations conducted on an individual ship basis provided the experience necessary to make the detailed plans for the large scale activations which were to follow. Detailed activation reports were prepared by the Reserve Fleet Group conducting the activation; by the industrial activity assisting with the activation, if such assistance was necessary; and by the Commanding Officers of the vessels activated. All special problems encountered, no matter of what nature, were delineated in these reports. The reports were then given widespread distribution to all activities that would possibly have some part in future activations of large numbers of vessels. All problems were given immediate and thorough study by the many activities concerned, and for the most part corrective measures and procedures were established. One problem that has not been solved as yet, is the previously mentioned case of incomplete machinery and equipment records on board vessels in the Reserve Fleets. This deficiency oftentimes gives rise to the condition that late in the activation period, when all machinery and equipment is activated, the need for extensive repair work to some major item of machinery or equipment is discovered. This condition is unfortunate inasmuch as it is one that could have been readily corrected at some previous time during the inactivation period or that could have

been included in the activation planning for the particular vessel involved. When discovered late in the activation period a condition such as this interrupts the normal sequence of events leading up to the vessel's becoming an active member of the fleet and is usually more costly to correct due to the time conderations involved.

The inactivation program has fulfilled its mission of maintaining vessels in a satisfactory material condition; and providing vessels for the active fleet when needed. Even with the changes in military characteristics required of warships to meet ever-changing naval techniques, the Reserve Fleet can supply at any time, the basic hull structures and equipment for the new type vessels. Many vessels from the Reserve Fleet have been converted after activation to become the most modern vessels of our present day Navy. These conversions have been accomplished at tremendous savings in regard to both time and money as compared to the building of completely new vessels. The Reserve Fleet has been an investment that has proven its value as a potential that can be brought into service when needed.

THE DEVELOPMENT OF ENGINEERING AS A PROFESSION

ACKNOWLEDGMENT

This paper is reprinted from the March 1951 issue of "Electrical Engineering." Its author is MR. R. D. HENSON, instructor in engineering law at the University of Illinois. The article discusses the historical background of the engineering profession, the beginnings of the engineering societies, and the development of engineering schools.

Recently an Illinois town installed parking meters with the agreement that "professional men" should be granted parking privileges at a fixed rate per month. When a local engineer applied for this professional license, he was at first refused on the ground that he was not a "professional man." On reconsideration, he was reluctantly granted a license along with the local lawyers and medical practitioners, but the town officials are still not convinced that an engineer possesses professional status. No doubt the same reaction would occur if a similar situation arose in most American towns and cities.

Some ideas have not changed much since 1711 when Joseph Addison wrote in *The Spectator:* "I am sometimes very much troubled when I reflect upon the three great professions of divinity, law, and physic; how they are each of them overburdened with practitioners, and filled with multitudes of ingenious gentlemen that starve one another." In the thinking of many people there are still just these three professions, although a person holding such an opinion would find no incongruity in including surgery with medicine today. The idea that engineering is a profession would startle some people as much as the idea that engineering is not a profession would startle most engineers. Engineers have been working for professional recognition for a long time. Why have they not succeeded?

EARLY HISTORICAL BACKGROUND

Not so long ago Nicholas Murray Butler said, "The best definition of engineering that I have ever seen is that it is the direction of the sources of the power of nature, the bridge over which man passes to get into nature to control it, to guide it, to understand it, and the bridge over which nature and its forces pass to get into man's field of interest and service." If this is what we mean by engineering—and the definition comes from the 1828 Charter of the Institution of Civil Engineers in England—then engineering as an art, science, craft, vocation, or what have you, is not new. Over 2000 years before Christ a hydraulic engineer in China was made emperor as a reward

for successfully devising a way to control flooding rivers. Almost 3500 years ago the great Egyptian engineer-architect Senmut was rewarded for his work by being made a nurse to Queen Hatshepsut's daughter. As long as we have had recorded history, men have been doing work which we today would classify as engineering, yet engineering is thought of as a newcomer to the professional ranks, when it is thought of as being a profession at all.

The reason for this is probably that it is only in comparatively recent times that we have had a distinct group of people practicing exclusively what we have come to call engineering, and it was only with the emergence of this group that we found a word to describe their activity. The Greek word "architect," meaning "chief builder," sufficed through many centuries to describe a person who was a builder in a very broad sense; that is, one who erected buildings, constructed irrigation works, built ships and machines, and did much work that today would be considered in the field of engineering.

A "Superintendent of Works," who had charge of the construction and repair of public edifices and roads, existed in Egypt as early as 3700 B.C., and the army officers who were well educated, performed all kinds of engineering work, from transporting stone to building canals, but there appears to have been no separate and distinct group of men who were educated for the sole purpose of practicing what would now be called engineering. Members of the nobility and the priesthood performed necessary engineering functions, if they were so inclined, simply because of their position, and in addition to other duties.

A similar situation prevailed in Rome. According to Plutarch, the first bridge over the Tiber was built by the first king of Rome, Ancus Marcius, who reigned from 641 to 616 B.C., and its custody and maintenance were attached to the priesthood. Later when the Roman Empire was formed, the building of roads seems to have passed to the soldier-engineer who was present when the need for roads arose. From the downfall of Rome in the fifth century to the beginning of the 16th century, the sciences were almost lost, except in so far as they were kept alive by the monks and other religious organizations.

NONSECULAR CHARACTER OF UNIVERSITIES

Law, divinity, and medicine fulfill needs which are felt by even the most primitive of peoples; engineering as engineering does not. Moreover, in an advanced civilization practitioners of divinity, law, and medicine tend to be learned men who draw attention to their work, while until recently, historically speaking, it was more important for engineers to be inventive and ingenious than for them to be able to read and write. (James Brindley, a very famous English engineer of the 18th century, was practically illiterate, which makes his accomplishments all the more remarkable, for he was largely unable to profit by the recorded experience of others.)

The word "engineer" apparently came into existence in the 14th century to refer to military men who were doing work of a civil character and the term "civil engineer" has been used ever since the 18th century to distinguish the civil from the military branch of the work. But when civil engineers, in an antithetic sense, came to be recognized in England, they were not the educated men of the time. Indeed, even after the Renaissance the Universities of Oxford and Cambridge did not include in their curricula subjects which had any practical application to engineering problems, and this is not surprising. At this time the influence of the Church over the English universi-

ties (and Continental universities, for that matter) was tremendous. Students were clerks and, after finishing their training at the university, if they chose to go on in the vocations which have since become recognized as professions, the taking of minor or major orders was usually necessary for advancement, for the king or bishop found conferring an ecclesiastical office less expensive than paying a salary. Such was the position of the physician, the lawyer, the teacher, the adviser. (By the 15th century, the Inns of Court were established in England so that secular lawyers were no longer directly under Church influence; the surgeons were organized in a secular guild in the 14th century, but their social position declined; and by the middle of the 16th century surgery was no more than a trade, the surgeons and barbers being united into a single guild with tooth-drawing as their practice in common.) With the exception of teaching, however, the professions largely had become secularized by the end of the 16th century.

THE THREE PROFESSIONS

The word "profession" came into use in the 16th century to denote particularly the learned vocations of divinity, law, and medicine, and at this time engineering as we think of it could scarcely be said to have awakened from the Dark Ages, so it could not possibly have been ranked with these three ancient and honorable vocations.

When Addison wrote about the three professions, he expressed the social feeling of his time, for the professions were thought to be solely for gentlemen. The Church influence is obvious, for medicine and law had in the recent past been closely associated with divinity. The professions today are intimately related to the business of living, as they were in Addison's time, although the very personal relation of lawyer and client, physician and patient, and engineer and client, is no longer as close as it once was, due to the complexities of life brought about by the emergence of engineering—an emergence so important and violent as to give to the period the name of the Industrial Revolution.

DEVELOPMENT OF PROFESSIONAL RECOGNITION

The type and extent of engineering development have always depended principally upon reaching such a state of civilization that a need created by the physical environment is recognized and, economically speaking, is capable of solution. This was true in ancient Egypt where irrigation was developed to make use of the annual overflowing of the Nile. The aqueducts of the Romans met an environmental need when the Romans had reached a stage of development in which they could recognize a need existed that could be satisfied. When the state of civilization declined, engineering progress ceased, and it remained dormant during the Dark Ages, for the most part. Civil engineering reappeared in Italy in the middle of the 17th century due to a demand to drain the swamps, and it developed in France at about the same time because of the need of an internal communication system in the development of commerce. In England engineering growth was made possible by the accumulation of wealth which followed the great period of exploration and discovery, and it "burst into full flower" after Watt's invention of the steam engine.

In the early 18th century in England the millwrights were the only engineers, and in the country these millwrights had to solve engineering problems as they arose, and solve them they did—by using their own resources and imagination. As the need for mechanical skill increased with the progress of manufacturing and agriculture, these men met the increasing needs with increasing skill; they became learned in their fields; and by 1771 they had reached such a stage in their development that the Society of Civil Engineers was founded as a dining club where they could exchange ideas. This date marks an important step in the emergence of engineering as a profession, for it is a step along the way traveled by the great, acknowledged professions.

What we now think of as a profession may be said to come into existence when a number of persons are found to be exercising a particular technique, based on a specialized training of a high intellectual caliber, whose practice must require the exercise of intelligence and discretion. And when widely recognized professional groups have emerged in our Anglo-American society, they have followed a fairly common pattern.

As the various groups which are classified as professional have emerged with their specialized intellectual training, professional associations have been formed at such time as the practitioners realized that they possessed a certain craft that should be distinguished. The public at large is not apt to recognize that those possessing certain qualifications are alone entitled to be called by a particular name, and the desire of the well qualified to separate themselves from the ill- or unqualified leads to a professional association formed from those possessing certain minimum qualifications. A professional association is based on a common subject interest, of course, but it is not formed for the purpose of study alone. If it were, it would be a subject association, many of which exist. A study of subject matter is only part of the work of a true professional association; it is not the sole object.

In addition to the desire to separate the qualified from the unqualified, there is another motive; to distinguish the scrupulous from the unscrupulous by setting up and maintaining a proper standard of conduct. This not only protects the public but also gives the profession a good name. Incidental to the raising of qualifications for members of the group, the problem of educational preparation arises, and the profession exerts its influence here.

Whether expressed or not, a strong incentive toward association is the raising of the status of the members of the group. The newcomers to professional ranks are looked down upon and not accepted as professionals until they have convinced the public that they alone are qualified to render certain services.

FIRST SOCIETIES FORMED

These steps toward professional recognition were followed by the engineers in England. The Society of Civil Engineers, founded in 1771, did not satisfy existing needs, so the Institution of Civil Engineers was founded in 1818 as a study association, but, as time went on, it broadened its interests and became a true professional association. As specializations in engineering multiplied, various specialist associations were formed, but not as rivals of the parent either in interest or membership.

In the United States the first successful national organization was the American Society of Engineers and Architects, founded in 1852, inactive from 1855 to 1867, and then revived as

the American Society of Civil Engineers (ASCE). This Society, by a constitutional amendment in 1873, made eligible for membership "Civil, Military, Geological, Mining and Mechanical Engineers, Architects, and other persons who, by profession, are interested in the advancement of science." This attempt to be all-inclusive failed, however, as The American Society of Mechanical Engineers was founded in 1880 because it was felt that the existing societies were not suited to a discussion of mechanical engineering problems, and the American Institute of Electrical Engineers was founded in 1884. (The American Institute of Mining Engineers was founded in 1871 and instead of merging with the ASCE after the amendment of 1873, continued its independent existence, changing its name in 1919 to the American Institute of Mining and Metallurgical Engineers.) With the growth of the many recognized specialties now existing in engineering, new societies have been formed as rapidly, it would appear, as new names could be thought up. The result is that there is no one organization which can speak authoritatively for all engineers.

While all lawyers do not belong to the American Bar Association (ABA) and all doctors do not belong to the American Medical Association (AMA), this seldom seems to be noted when either group takes a stand on a public issue. These organizations are unquestionably professional associations. They have a common subject interest, they have standards of conduct, they are concerned with the qualifications of their members, and, if they no longer need be concerned with raising the status of their members, they at least attempt to preserve the status quo. No one engineering organization even remotely approaches the influence of the ABA or the AMA, for no one engineering organization really represents all engineers. The need for a unified organization is widely felt today, but the need has not yet been met.

That engineering societies are interested in the qualifications of those practicing engineering is shown not only by the qualifications set up by the individual groups for their members, but also by the work done to have registration laws passed in all the states. If there is any need for registration of engineers so far as the public is concerned, it is not analogous to the licensing of lawyers, physicians, surgeons, or dentists, any of whom may be needed at a moment's notice to provide some essential service when there may not be time to investigate the qualifications of the person called. Moreover, while licensing laws set up a minimum standard for those to whom they apply, all engineers are not now covered by these laws. Licensing alone does not make a profession, however, for if it did midwives and funeral directors and plumbers would belong to professions, and no matter how essential those occupations may be they are not professions. The existence of the Engineers' Council for Professional Development (ECPD) and the American Society for Engineering Education shows the interest engineers have in these fields. It is significant that the Report of the Committee on Professional Recognition of the ECPD included as one of the attributes of a profession, "It must have group consciousness for the promotion of technical knowledge and professional ideals and for rendering social services." If a set of ethics, such as has been formulated by the ECPD, were inculcated into the engineering student, the inimicality of his belonging to a labor union would be more apparent to him when he goes into the practice of engineering.

Lawyers and doctors have single organizations which perform the work of the several engineering subject associations plus the work of the special purpose

groups, and their results are worth emulating, at least if engineers desire general recognition for their profession. For engineering certainly is a profession by the generally accepted standards; what is lacking is widespread public recognition of the accomplished fact.

DEVELOPMENT OF ENGINEERING SCHOOLS

Education has created the problem and in education lies the answer. A profession requires education. Only when engineering began to require specialized intellectual training did it begin to emerge as a profession, but while education has made engineering a profession, it has also inhibited its growth as such. In the United States of 100 years ago, engineering schools trained bridge, road, and railroad builders, while most engineers were trained in shops or else took the conventional Bachelor of Arts course with a few courses in engineering. The trend in engineering education has been from the general to the specialized back to the general.

The first curriculum offered at Rensselaer Polytechnic Institute in 1824 took one year for completion and was divided into three terms. "School opened the last week in July with an 'experimental term,' during which the students gathered botanical, mineralogical, and zoological specimens, visited shops and factories near the school, and discussed with the class the significance of what they had collected and observed. In addition each student gave a number of lectures on chemistry and natural philosophy, fully illustrated by experiments performed with his own hands. During the second term, from the end of November to the first of March, the students reviewed in class the sciences taught in the fall, and in addition studied rhetoric, logic, geography, and mathematics. The spring term lasted from the first week in March to the end of June. For six weeks the work consisted of lectures by the students on experimental philosophy, chemical powers, substances non-metallic, metalloids, metals, soils, and mineral waters. For the remaining nine weeks the students were exercised in the application of the sciences to practical projects and in the study of engineering works in the neighborhood of the school."

The Rensselaer Institute changed from a school of natural science designed to train teachers into a school of engineering and technology, and its curriculum was revised from time to time, a new curriculum being adopted in 1849 to incorporate some ideas from the more theoretical French schools, and the course was lengthened to three years, the first half being used to give a general scientific basis of all engineering and the second half being devoted to specialization.

When engineering curricula were adopted later by other schools, the Rensselaer influence loomed large. The curriculum adopted at the University of Illinois in 1867 for the first three years included in the first year algebra, geometry, trigonometry, descriptive geometry and drawing, English or foreign language, history, and botany; in the second year analytics, calculus, descriptive geometry, drawing, surveying, foreign language; and in the third year calculus, analytic mechanics, descriptive astronomy, railroad surveying, shades, shadows, perspective, physics, and chemistry. The fourth year was devoted to more technical courses. At Illinois the instruction in theory was by lecture and recitation from textbooks, and plates and models were used, along with shopwork allowing the construction of machinery which had been planned in the drafting room. In the

process of constructing machinery, the students earned money sufficient in some cases to pay their expenses. At Rennselaer by 1865 the method of instruction was by questioning and blackboard demonstration, rather than the student instruction which had formerly been used.

With the establishment of more engineering schools, the problem of a proper education received due attention. At the annual meeting of the ASCE in June, 1874, Mr. Thomas C. Clarke read a paper on "The Education of Civil Engineers" in which he said that the object of education "is to enable us to know ourselves and to know the laws of nature. . . . Those persons who have come to the study of Civil Engineering after a thorough training in both natural science and also, to use the good old expression, 'the humanities,' are those who make the most rapid progress. When a man has learned how to learn, he can quickly learn anything." Despite the merit in this view, the trend in education turned more toward specialization, a natural result of new developments in engineering and of the growth of a body of teachers who had received an engineering education, as the early teachers had not.

PROBLEMS OF SPECIALIZATION

The problem of specialization has not been confined to engineering but has invaded almost all fields of knowledge. The recent Harvard report on "General Education in a Free Society" stated: "It would seem clear that communication on an advanced level is impossible unless those who are seeking to communicate with each other have some common body of knowledge and ideas, as well as some training in the analysis of values and of relationships. The undergraduate, whether he be a concentrator in the sciences, the humanities, or the social sciences, should be able to talk with his fellows in other fields above the level of casual conversation. He should share in a common awareness of the importance of ideas and objectives, in a common understanding of the heritage which is the possession of his generation. Nor will general education at the college level have been entirely successful unless the student has acquired some understanding of the principal respects in which their aims and methods differ."

The opposition to a liberal education can be traced to historical causes, for liberal education arose in a slave-owning society like ancient Athens where the ruling class did nothing, but had a liberal education so as to enjoy life, each in his own way, while the slaves were trained in specialized work. Such a society no longer exists but the need for that type of education has not disappeared. "Democracy is the view that not only the few but that all are free, in that everyone governs his own life and shares in the responsibility for the management of the community. This being the case, it follows that all human beings stand in need of an ampler and rounded education." While specialization is a product of our society, "in order to discharge his duties as a citizen adequately, a person must somehow be able to grasp the complexities of life as a whole. . . . The aim of education should be to prepare an individual to become an expert both in some particular vocation or art and in the general art of the free man and the citizen. Thus the two kinds of education once given separately to different social classes must be given together to all alike."

Besides the civic duties which have gone unheeded because specialization in engineering gave no time to arouse an educational interest in them, social and business deficiencies have also handi-

capped the specialist. Recognition of these factors has started a trend back to general education in the undergraduate curriculum with specialization at the graduate level. President Davis of Stevens Institute of Technology has observed that adaptability has become increasingly more important to the young graduate than proficiency in a particular field because of the rapid changes now being made. Besides the new and, at present, unknown fields which may be opened up, fields of specialization which now seem important may not present the same opportunities in a few years. Thus a broad general background in science and engineering becomes increasingly more important.

Lawyers and doctors have succeeded in their fights to require a combination of unspecialized undergraduate and specialized graduate training, so it is not unnatural for engineers to follow this lead, feeling themselves entitled to similar respect as members of a profession.

Some elimination of courses in the engineering curriculum has been made possible by differentiating between creative work and techniques, reserving the former for the engineering school and the latter for the trade schools. Engineering schools have been further aided by the large industrial companies which have training programs to teach their young employees any necessary techniques. The problem of further elimination of unnecessary courses has been stated with unusual frankness by Dean Finch of Columbia: "Unfortunately, faculty members interested in a particular branch of engineering have clung tenaciously to the belief that any student who received a degree in their branch must be required to take practically all the application courses in special techniques which had accumulated over the years and were traditionally regarded as within the scope of this branch. This was a natural reaction. These were the specialties to which many teachers had devoted their entire interests, teaching efforts and careers, and on which such reputation as they had achieved rested."

The aim of a general education is at least in part to allow all of us to share our common heritage and to understand the world and each other better. A narrow, technical education, instead of furnishing an incentive for its recipient to read widely and to investigate others' problems on his own initiative, probably tends to make one more reclusive than ever. The tendency of a narrow education to cause narrow interests may account for the lack of interest shown by most engineers in public affairs, and, consequently, due to a lack of a single association which can speak for all engineers on public matters, for the failure to include a single engineering or scientific society among more than 40 organizations chosen by the United States Government to attend the United Nations Conference in San Francisco—to mention only one instance when engineers could have made a contribution to the world but did not.

Recognizing the deficiencies which unquestionably exist in engineering education, the trend is toward a general education, with specialization at the graduate level. The undergraduate education is general both as to engineering subjects and as to other fields of knowledge. In time, when the many have acquired the interests held now by the few, the need for a great, unified organization will be met, and the engineers will receive proper recognition as professional men. The public expects leadership from members of a profession, and engineers individually and collectively must be prepared to meet that expectation and to fulfill their obligations with distinction.

Will engineering ever become a profession in the eyes of the public? The answer may lie in a paraphrase of an old saying: "United we can, divided we fail."

DISCUSSION

BY CAPTAIN P. C. GOLD, JR., USN

of "The Education of Naval Engineers" by Captain Guy Chadwick, USN (Ret.)

The education and training of Naval Engineers is a subject that invariably invites controversy. Captain Chadwick has expressed in an excellent manner a plea for less specialization. The paper is especially timely for we should decide now if changes are needed. The ships being designed today are of such complexity that we will be unable to "know our ship" as we have in the past. As Captain Chadwick states, we cannot specialize in everything.

If the four-year college, or Naval Academy education would assure graduates a clear grasp of basic principles, a thorough knowledge of engineering fundamentals, perhaps our postgraduate time could be better spent and we could approach the ideal, the specialist in warship engineering.

What is the best end product that we can hope for with only three years of postgraduate study available? Captain Chadwick considers that the Naval Engineer must be capable of providing and maintaining propelled hulls suitable to carry and serve guns and planes, communications, personnel and cargo, singly or in combination, of designing ships as an informed engineer able to anticipate future needs. I agree with the concept, but fear that it is not possible of accomplishment.

The tug-of-war between the broad versus the narrow education, the practical versus the theoretical, is never ending. The optimum compromise for the Naval Engineer is obscure. Whatever the solution may be, I disagree with the thought that "he should guard against stealing time from primary studies for use in tempting background excursions." A good general engineer, intimate with one specialized field, is, I believe, the better solution. If we can obtain sufficient fundamental engineering knowledge to insure clear logical thinking, ability to express those thoughts, a reasonable understanding of the elements of the ship, and intimate knowledge of a specialty, we have certainly an acceptable solution.

The paragraphs on the selection of postgraduate students point out the need for the stimulation of the desire to be Naval Engineers among midshipmen and young officers. This is especially important now when the thought of technical training is in competition with the thought of more glamorous wartime operations. These young men must be made to recognize their opportunities. If enthusiasm and curiosity are created from a desire to specialize, that should be encouraged. We can attain our goal and still find time for nuclear physics or other popular specialties if that is what is required to maintain enthusiasm. The job is easy if the desire to learn is there.

The pedagogical philosophy included under "The Educational Process, Skills, Facts, Reasoning Power," presents excellent thoughts which should be useful to any engineering teacher. The absorption of these skills and facts must continue however throughout the service career of the Naval Engineer.

If the curriculum furnishes the Naval Engineer with the fundamentals of engineering sufficient to give him the courage to investigate any problem in any engineering field, if it allows him time to obtain unusual information in a specialized field of his choice, if it stimulates his mind so that he recognizes in the years of formal education he has but only started, that his education is always incomplete, it is a good curriculum.

At the Boston Naval Shipyard, where I work, I find that the representatives of the educational system of recent years are excellent and capable Naval Engineers, a very satisfactory "end product." The continued recruitment of men of their caliber is a more serious problem. Also, the fruit of our efforts, the warships of today, when compared to those of other nations, type by type, is to my mind proof of the effectiveness of our past Naval Engineering educational system. We must be mindful, however, of the increased complexity of the warship of tomorrow and allow increasing specialization, not less.

The Society has learned with deep regret of the death of the following since the publication of the February, 1952, issue:

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1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

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6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

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Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which insufficient material is already on hand.

SUBJECT MATTER AND AUTHORS

To assist the editor in programming future issues, the help of all members is solicited. To make it easy, the last page in this issue is readily detachable as you will find. This page has blanks for two entries.

(a) What subject would you, as a member, like to see covered by an article in the JOURNAL.

and

(b) Who do you consider best qualified to prepare such an article authoritatively, and what is his address (if you know).

Any of these forms which are filled in and mailed to the Society will be received with thanks and the editor will follow up to get the suggested articles prepared.

PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

LIFE MEMBERSHIPS

Any member may now purchase a life membership under the following rules:

(a) Any dues paid for the year in which life membership is purchased will be credited to the cost of the life membership.

(b) Life memberships are non-transferable and terminate with the death of the member.

(c) No refund will be made on account of death or resignation of a life member.

(d) Life membership will vary in cost with the age of the member at his next birthday following application, as follows:

Over 55 years	$125.00
40 to 55 years	175.00
25 to 39 years	225.00
Under 25 years	250.00

(e) All life memberships paid in shall be protected by a transfer on the books of the Society of Series G, U. S. Government 2½ per cent bonds. Thus a life membership will be established. It will be credited with moneys paid in for life memberships and debited with the regular amount of annual dues for each life member each year.

LOCAL CHAPTERS

Local Chapters of the American Society of Naval Engineers may now be authorized by the Council. The following rules for recognition of Local Chapters have been adopted by the Council:

(a) Twenty or more regular members, Naval or Civilian, may apply for a Charter as a Local Chapter.

(b) Each application must be accompanied by a list of members and a copy of local By-laws. The latter must meet the following minimum requirements.

1. All financial dealings of the local Chapter must be independent of the Society and can in no way obligate the Society as a whole. The local chapter shall set up on a non-profit basis. All accounting shall be local.

2. Each active local Chapter shall receive from the Society a grant of $0.50 per year for each naval member, civil member or associate who resides in the local area and who associates himself with the local Chapter. This grant may be used by the local Chapter to defray any necessary expenses, including (a) Letterheads, (b) Notice cards, (c) Postage, (d) Minimum rental allowance, (e) Secretarial service (part time).

3. Any technical papers presented at local chapter meetings, shall be submitted to the Secretary-Treasurer of the Society for consideration for publication in the JOURNAL. Any paper accepted will be paid for at regular rates.

4. Each local chapter shall submit a quarterly report of its activities to the Secretary-Treasurer. These reports must reach Washington, D. C. prior to 15 January, 15 April, 15 July and 15 October. This report shall contain a list of active local members as of the first day of the quarter for the purpose of computing the amount of grant.

5. Associate members of the Society shall be eligible for membership in a Local Chapter, entitled to all the privileges of other members except voting and holding office.

Permission is granted to reprint any original article contained herein if the following conditions are met:

a) Credit is given to the JOURNAL with reference to the issue.

b) Credit is given to the author.

c) If the author is a military officer or a civilian employe of the Department of Defense, the following note shall be carried:

"The views expressed herein are the personal ones of the author and are not necessarily the official views of the Department of Defense or of a Military Department."

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

Financial Statements, 1951

Statement of Income and Expenditures

Expenditures

Publications:		
Printing	$30,822.62	
Engraving	2,537.31	
Manuscript	2,765.00	
Manuscript in Advance	135.00	
Postage	382.97	
Commission	125.75	
Exchange	1.25	$36,769.90
Salaries		5,910.00
General Expense		2,438.97
Current Profit and Loss		2,516.04
Banquet, 1951		636.09
Banquet, 1952		51.25
		$48,322.25

Income

Publication:			
Advertisements	$ 7,612.50		
Dues	21,362.64		
Sales (General)	663.02		
Sales (Buttons)	15.50		
Subscriptions	15,735.75	$45,389.41	
Interest on Investments		1,525.00	$46,914.41
NET LOSS			$ 1,407.84

THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

FINANCIAL STATEMENT, 1951

BALANCE STATEMENT

Total Assets January 1, 1951.....			$59,680.91
Assets December 31, 1951:			
Cash		$ 1,618.14	
Accounts Receivable:			
Advertisements	$ 3,219.95		
Dues	2,055.65		
Sales	227.26		
Subscriptions	376.25	5,879.11	
Investments (Bonds):			
U.S. Defense, Series G 2½%.....		58,000.00	
Washington Gas Light Co. 5%.....		997.50	
Furniture		140.82	
		$66,635.57	
Liabilities (Accounting Only)			
Advertisements paid in advance.....	$ 112.50		
Dues Paid in Advance.....	372.25		
Subscriptions Paid in Advance.....	7,877.75	8,362.50	
Net Assets December 31, 1951.....			58,273.07
NET LOSS			$ 1,407.84

Respectfully submitted,

/s/ J. E. HAMILTON,
Secretary-Treasurer

Audited and Found Correct:

/s/ FRANK G. LAW
/s/ CHARLES G. COOPER } Audit Committee
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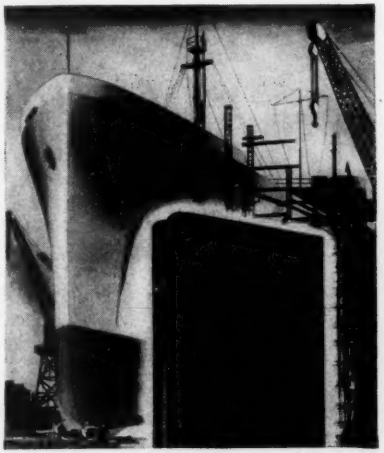

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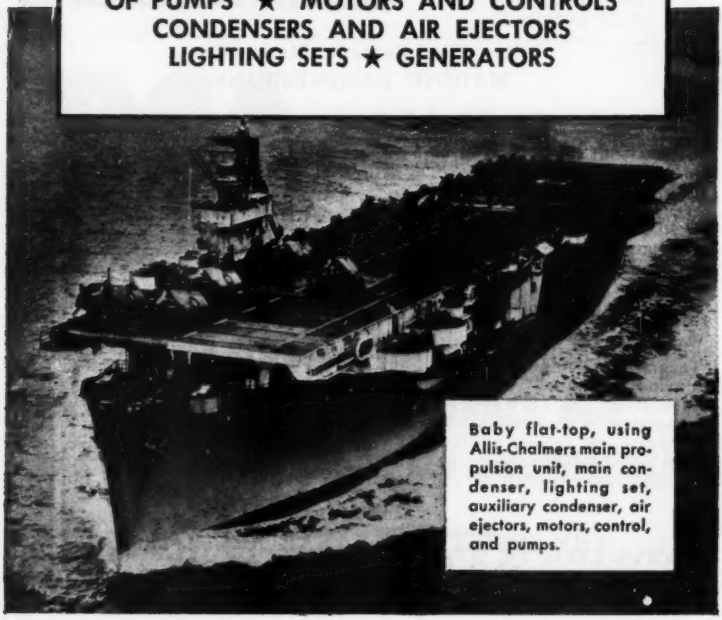

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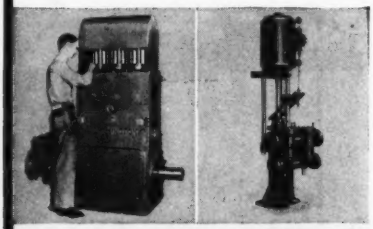

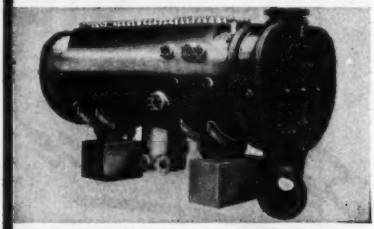

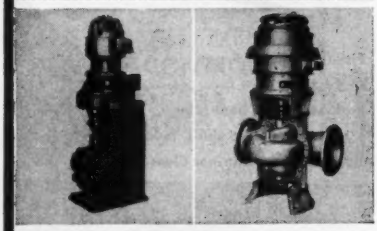

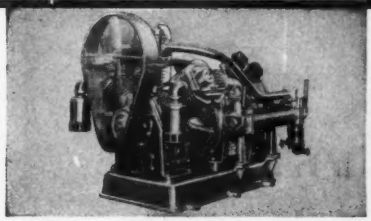

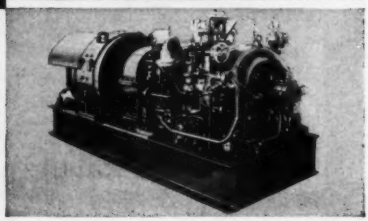

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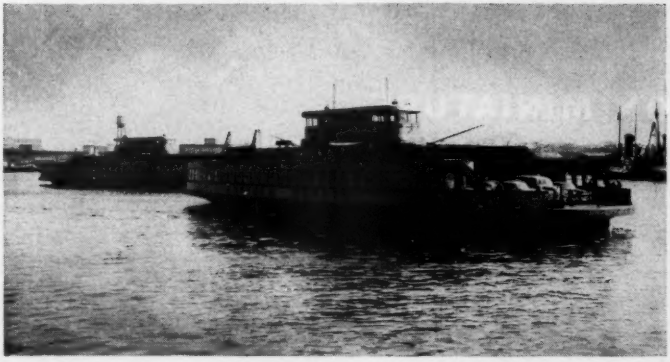

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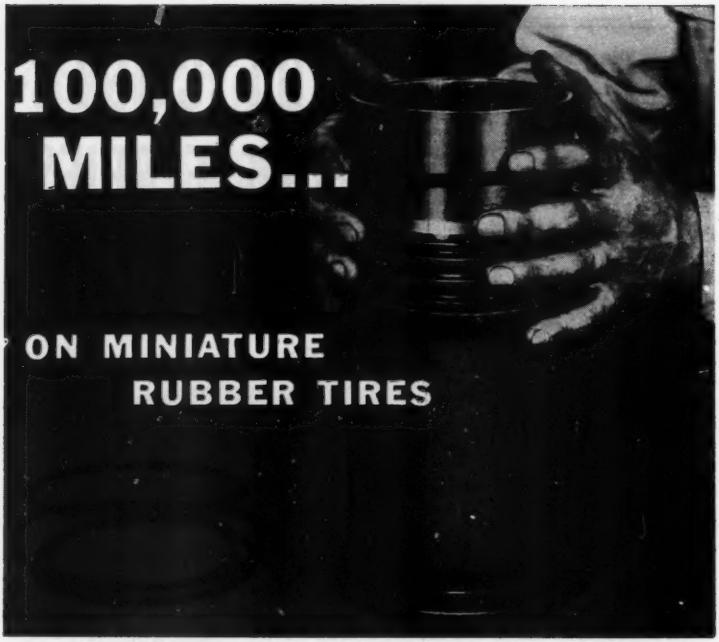

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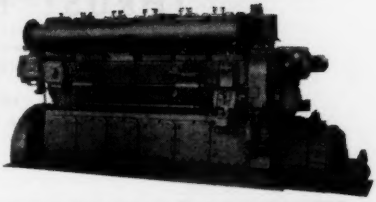

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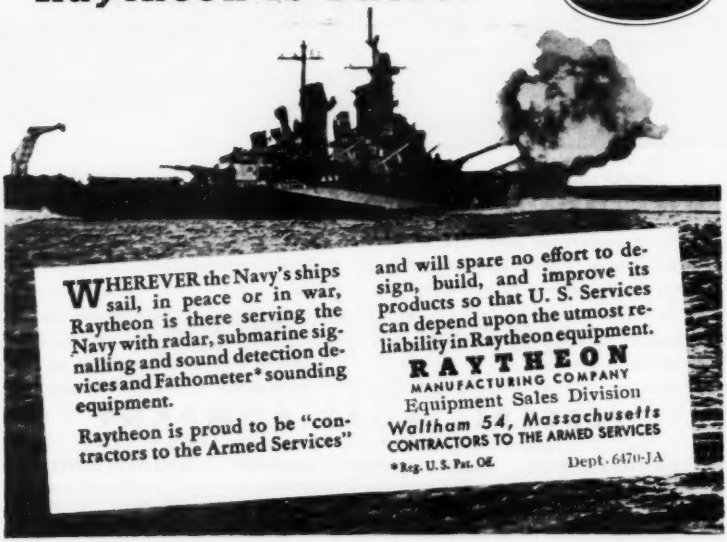

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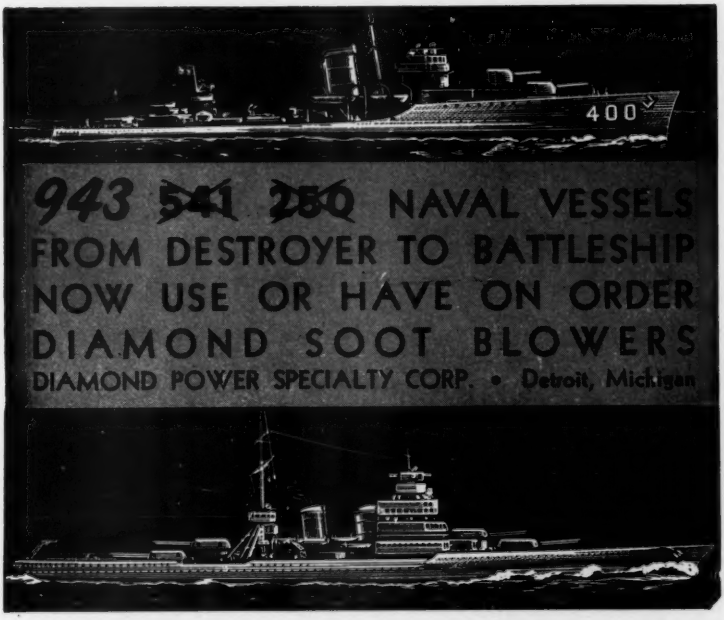
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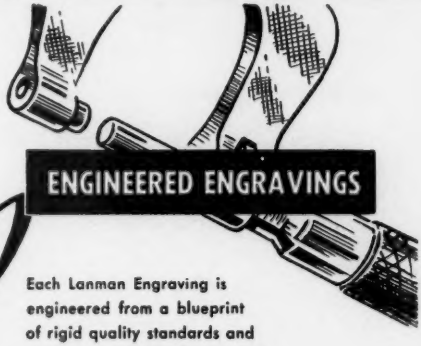

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I would like to see an article in the JOURNAL of the following subject:

_____

_____

I suggest that _____

_____ could prepare an authoritative article on the above subject.

_____
Member

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(First) (Middle) (Last)

Name .....

Rank..... File No.....

Business connection and position, if any.....

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Name .....

Years in engineering work.....

Years in responsible charge of important work.....

Present business connection and position.....

Recommended by (two members).....

.....

For Associate Membership

(First) (Middle) (Last)

Name .....

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Business connection and position.....

Recommended by (one member).....

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Signature of Applicant

Address for Journal and Mail

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MAIL TO SECRETARY-TREASURER
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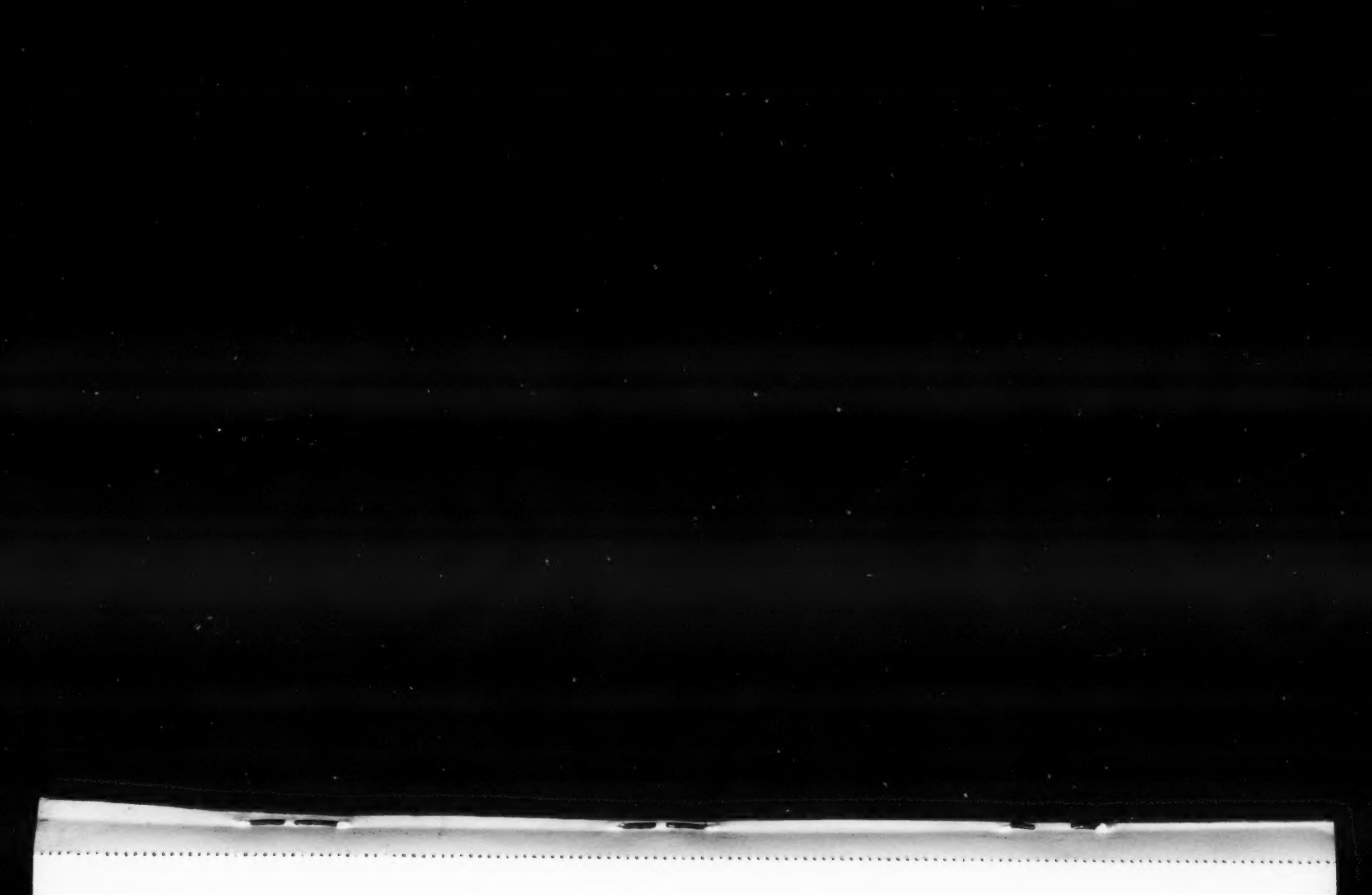
*See reverse side for required qualifications for various classes of membership



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